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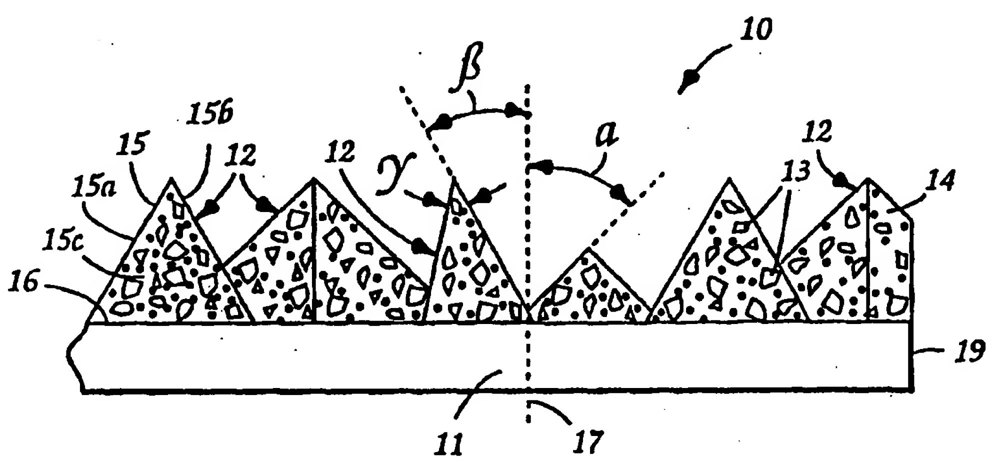

(57) Abstract

An abrasive article (10) is provided having a sheet-like structure having a major surface (16) having deployed in fixed position thereon a plurality of abrasive three-dimensional abrasive composites (12), each of the composites comprising abrasive particles dispersed in a binder (14) and having a precise shape defined by a distinct and discernible boundary (15) that includes specific dimensions, wherein the precise shapes are not all identical. The invention also relates to methods for manufacturing such an abrasive article (10), including the production tool and production tool master used in the scheme of manufacturing the abrasive article (10).

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ABRASIVE ARTICLE, METHOD OF MANUFACTURE OF SAME, METHOD OF USING SAME FOR FINISHING, AND A PRODUCTION TOOL

TECHNICAL FIELD

This invention relates to an abrasive article having a sheet-like structure having a major surface having deployed thereon a plurality of abrasive composites having precise shapes, wherein the precise shapes are not all identical. The invention also relates to methods of manufacturing an abrasive article, and a production tool used to manufacture such an abrasive article, and a method of using such an abrasive article to reduce a surface finish.

BACKGROUND ART

In general, abrasive articles employ a plurality of abrasive particles which are bonded together as a unitary structure (e.g., a grinding wheel) or bonded separately to a common backing (e.g., a coated abrasive article). While these types of abrasive articles have been utilized to abrade and finish workpieces for many years, problems remain in the field.

For instance, one persistent problem confronting the abrasive industry arises from the generally inverse relationship associated between the cut rate (i.e., the amount of workpiece removed for a given time interval) and the finish that is imparted by the abrasive article on the workpiece surface. That is, it is difficult to design an abrasive article that affords a relatively high rate of cut while concomitantly imparting a relatively fine surface finish on the workpiece being abraded. This explains the presence of a wide range of abrasive products in the market using coarse grit (i.e., relatively large particle size of abrasive particles) to fine grit (i.e., relatively small

particle size of abrasive particles). The use of these differently grit-sized abrasive products in a separate and sequential manner can provide some measure of success in ultimately achieving both a high cut and a fine finish, but the practice can be cumbersome and time consuming. Naturally, a single abrasive article which simultaneously would provide both high cut rate and fine finish would be more convenient and highly desired in the industry.

In addition to these goals, it has also been desired in the abrasive industry to provide an abrasive article which imparts a consistent surface finish in the workpiece while lessening or preventing scribing and/or chatter. Scribing refers to the occurrence of pronounced unwanted grooves in the workpiece surface which results in an increase in surface roughness units (Ra). Ra is the arithmetic average of the scratch depth. Typically, the grooves, when they occur, extend in the surface of the workpiece in a direction tracking the relative motion of the abrasive article vis-a-vis the workpiece surface. On the other hand, chatter means an undesirable repetive pattern created on the surface of a workpiece, usually at regular spaced intervals at a direction perpendicular to the direction of belt movement.

While various attempts have been made to create new and improved abrasive products, no complete solution to the problems noted above have been presented. While the following list of references describe a variety of abrasive products none is known to provide a completely satisfactory result to these problems.

More specifically, U.S. Patent No. 2,115,897 (Wooddell et al.) teaches an abrasive article having a backing and attached thereto by an adhesive are a plurality of blocks of bonded abrasive material. These

bonded abrasive blocks can be adhesively secured to the backing in a specified pattern.

U.S. Patent No. 2,242,877 (Albertson) teaches a method of making a compressed abrasive disc. The method involves embedding abrasive particles in a binder layer that is coated on a fibrous backing. Then, a mold die is used to impart a molded pattern or contour into the thickness of binder and particle layer under heat and pressure to form a compressed abrasive disc. The molded surface of the abrasive disc has a specified working surface pattern which is the inverse of the profile of the molding die.

U.S. Patent No. 2,755,607 (Haywood) teaches a coated abrasive in which there are land and groove abrasive portions, which can form, for example, an overall rectlinear or serpentine pattern. An adhesive coat is applied to the front surface of a backing and this adhesive coat is then combed to create peaks and valleys to pattern the surface of the adhesive coat. Haywood discloses that each of the lands and grooves formed in the adhesive coat by such a combing procedure preferably have the same width and thickness, but that they may be varied. Next the abrasive grains are distributed uniformly in the lands and grooves of the previously patterned adhesive coat followed by solidification of the adhesive coat. The abrasive particles used in Haywood are individual grains which are not used in slurry form with other grains in a binder. Therefore, the individual abrasive grains have irregular non-precise shapes.

U.S. Patent No. 3,048,482 (Hurst) discloses an abrasive article comprising a backing, a bond system and abrasive granules that are secured to the backing by the bond system. The abrasive granules are a composite of abrasive grains and a binder which is separate from the bond system. The abrasive granules

are three dimensional and are preferably pyramidal in shape. To make this abrasive article, the abrasive granules are first made via a molding process. Next, a backing is placed in a mold, followed by the bond system and the abrasive granules. The mold has patternized cavities therein which results in the abrasive granules having a specified pattern on the backing.

U.S. Patent No. 3,605,349 (Anthon) pertains to a lapping type abrasive article. The binder and the abrasive grain are mixed together and then sprayed onto the backing through a grid. The presence of the grid results in a patterned abrasive coating.

Great Britain Patent Application No. 2,094,824 (Moore) pertains to a patterned lapping film. The abrasive slurry is prepared and the slurry is applied through a mask to form discrete islands. Next, the resin or binder is cured. The mask can be a silk screen, stencil, wire, or a mesh.

U.S. Patent No. 4,644,703 (Kaczmarek et al.) concerns a lapping abrasive article comprising a backing and an abrasive coating adhered to the backing. The abrasive coating further comprises a suspension of lapping size abrasive grains and a binder cured by free radical polymerization. The abrasive coating can be shaped into a pattern by a rotogravure roll.

U.S. Patent No. 4,773,920 (Chasman et al.) concerns a lapping abrasive article comprising a backing and an abrasive coating adhered to the backing. The abrasive coating comprises a suspension of lapping size abrasive grains and a binder cured by free radical polymerization. The abrasive coating can be shaped into a pattern by a rotogravure roll.

U.S. Patent No. 4,930,266 (Calhoun et al.) teaches a patterned abrasive sheeting in which the abrasive granules are strongly bonded and lie substantially in a

plane at a predetermined lateral spacing. In this invention the abrasive granules are applied via a impingement technique so that each granule is essentially individually applied to the abrasive backing. This results in an abrasive sheeting having a precisely controlled spacing of the abrasive granules.

U.S. Patent No. 5,014,468 (Ravipati et al.) pertains to a lapping film intended for ophthalmic applications. The lapping film comprises a patterned surface coating of abrasive grains dispersed in a radiation cured adhesive binder. The patterned surface coating has a plurality of discrete raised three dimensional formations having widths which diminish in the direction away from the backing. To make the patterned surface, an abrasive slurry is applied to a rotogravure roll to provide a shapes surface which is then removed from the roll surface and then the radiation curable resin is cured.

U.S. Patent No. 5,015,266 (Yamamoto) pertains to an abrasive sheet by uniformly coating an abrasive adhesive slurry over an embossed sheet. The resulting abrasive coating has high and low abrasive portions formed by the surface tension of the slurry, corresponding to the irregularities of the base sheet.

U.S. Patent No. 5,107,626 (Mucci) teaches a method of providing a patterned surface on a substrate by abrading with a coated abrasive containing a plurality of precisely shaped abrasive composites. The abrasive composites are in a non-random array and the abrasive composites comprise a plurality of abrasive grains dispersed in a binder.

U.S. Patent No. 5,152,917 (Pieper et al.) discloses a coated abrasive article that provides both a relatively high rate of cut and a relatively fine surface finish on the workpiece surface. The structured abrasive of Pieper et al. involves precisely

shaped abrasive composites that are bonded to a backing in a regular nonrandom pattern. The consistency of the profile of the abrasive composites provided by the abrasive strucutre of Pieper et al., among other things, helps provide a consistent surface finish in the worked surface.

Japanese Patent Application No. S63-235942 published March 23, 1990 teaches a method of a making a lapping film having a specified pattern. An abrasive slurry is coated into a network of indentations in a tool. A backing is then applied over the tool and the binder in the abrasive slurry is cured. Next, the resulting coated abrasive is removed from the tool. The binder can be cured by radiation energy or thermal energy.

Japanese Patent Application No. JP 4-159084 published June 2, 1992 teaches a method of making a lapping tape. An abrasive slurry comprising abrasive grains and an electron beam curable resin is applied to the surface of an intaglio roll or indentation plate having a network of indentations. Then, the abrasive slurry is exposed to an electron beam which cures the binder and the resulting lapping tape is removed from the roll.

United States patent application No. 07/820,155 filed 13 January 1992 (Calhoun), which is commonly assigned to the owner of the present application, teaches a method of making an abrasive article. An abrasive slurry is coated into recesses of an embossed substrate. The resulting construction is laminated to a backing and the binder in the abrasive slurry is cured. The embossed substrate is removed and the abrasive slurry adheres to the backing.

U.S. Patent No. 5,219,462 (Bruxvoort et al.) teaches a method for making an abrasive article. An abrasive slurry is coated substantially only into the

recesses of an embossed backing. The abrasive slurry comprises a binder, abrasive grains and an expanding agent. After coating, the binder is cured and the expanding agent is activated. This causes the slurry to expand above the surface of the embossed backing.

United States patent application No. 08/004,929 filed 14 January 1993 (Spurgeon et al.), which is commonly assigned to the owner of the present application, teaches a method of making an abrasive article. In one aspect of this patent application, an abrasive slurry is coated into recesses of an embossed substrate. Radiation energy is transmitted through the embossed substrate and into the abrasive slurry to cure the binder.

United States patent application No. 08/067,708 filed 26 May 1993 (Mucci et al.), which is commonly assigned to the owner of the present application, teaches a method of polishing a workpiece with a structured abrasive. The structured abrasive comprises a plurality of precisely shaped abrasive composites bonded to a backing. During polishing, the structured abrasive oscillates.

The use of variable pitch sawing teeth has been disclosed as a cutting edge for a hack saw blade, such as mentioned in a trade advertisement distributed by Lenox Co. and entitled "Lenox Hackmaster V Vari-Tooth Power Hack Saw Blades", to provide balanced cutting action and quiet performance. This hack saw blade design is described as useful to saw metal bar stock, ganged workpieces, or work with holes, slots or interruptions. This hack saw blade design is not specifically disclosed as adaptable for frictional abrasion applications between two rubbing surfaces including a complex three-dimensional working surface, nor does the LENOX publication disclose the wherewithal therefor.

Although some of the abrasive articles made according to the aforementioned patents, viz. Pieper et al., might provide an abrasive article yielding both high rate of cut and relatively fine finish, it has been observed that scribing can occur in surfaces worked by some prior art abrasive articles when the abrasive articles are used. For instance, many abrasive articles have directional limitations insofar as how the articles are to be oriented relative to the work surface to be reduced, i.e., some articles cannot be used omnidirectionally. If used improperly by accident or neglect, e.g., if such an abrasive article is not properly aligned with the surface to be worked by the operator, these abrasive articles, among other things, can cause scribing in the worked surface.

Therefore, it can be understood that the abrasive industry would highly value a versatile high-cut rate, fine finish abrasive article which is more resistant to inadvertent scribing and more adaptable to a wider range of abrasive conditions.

DISCLOSURE OF THE INVENTION

The present invention provides an abrasive article which has a high cut rate yet imparts a relatively fine surface finish. The invention provides an abrasive article having a sheet-like structure having a major surface having deployed thereon a plurality of precisely shaped abrasive composites, wherein not all shapes are identical. The invention also provides methods of manufacturing the abrasive article, a production tool useful in such methods, and a methods of using the abrasive article to reduce surface finish.

In one embodiment, this invention relates to an abrasive article having a sheet-like structure having a major surface having deployed in fixed position thereon a plurality of abrasive three-dimensional abrasive composites, each of the composites comprising abrasive

particles dispersed in a binder and having a substantially precise shape defined by a substantially distinct and discernible boundary which includes substantially specific dimensions, wherein the precise shapes are not all identical.

In a further embodiment, substantially all of the aforesaid abrasive composites exist as pairs, each pair including two unmatched abrasive composites, one abrasive composite having a nonidentical shape to an adjacent abrasive composite.

Yet another embodiment of this invention relates to an abrasive article wherein the aforesaid abrasive composites include a first abrasive composite having a first precise shape having specific first dimensions and a second abrasive composite having a second precise shape and second specific dimensions wherein the first and the second specific dimensions are nonidentical.

In a further embodiment of the abrasive article of the invention, the aforesaid first and second abrasive composites each has a boundary defined by at least four planar surfaces wherein adjacent planar surfaces meet to define an edge of a certain length, wherein at least one edge of the first composite has a length which is different from the length of all edges of the second composite. In one further embodiment, the length of the at least one edge of the first composite has a length which varies with respect to the length of any edge of the second composite in a ratio between 10:1 to 1:10, not inclusive of 1:1.

In another embodiment of the abrasive article of the invention, the aforesaid first and second abrasive composites have a first and second geometrical shape, respectively, which are nonidentical. For example, the aforesaid first and second geometrical shapes can be selected from different members of the group of geometrical shapes consisting of cubic, prismatic,

conical, truncated conical, cylindrical, pyramidal, and truncated pyramidal.

In another embodiment of the abrasive article of the invention, each abrasive composite has a boundary defined by at least four planar surfaces wherein adjacent planar surfaces meet at an edge to define an angle of intersection therebetween, wherein at least one angle of intersection of the the first abrasive composite is different from all of the angles of intersection of the second composite. In a preferred embodiment, no angle of intersection of adjacent planar surfaces in the first abrasive composite is equal to 0° or 90°. In a further embodiment thereof, substantially all the abrasive composites have a pyramidal shape.

In another preferred embodiment of the invention, the surface of the abrasive article has a machine direction and opposite side edges, each side edge being parallel to the machine direction axis and each side edge being respectively within a first and second imaginary plane each of which is perpendicular to the surface, a plurality of parallel elongate abrasive ridges deployed in fixed position on the surface, each ridge having a longitudinal axis located at its transverse center and extending along an imaginary line which intersects the first and second planes at an angle which is neither 0° nor 90°, and wherein each abrasive ridge comprises a plurality of the aforesaid three-dimensional abrasive composites which are intermittently spaced along the longitudinal axis.

In a further embodiment of the abrasive article of the invention, the aforesaid plurality of parallel elongate abrasive ridges are deployed in first and second groups wherein the first and second groups are located at nonoverlapping locations in the in the machine direction or in a direction perpendicular to the machine direction of the major surface, wherein the

longitudinal axis of at least one abrasive ridge within the first group extends along an imaginary line that intersects with an imaginary line extending from at least one longitudinal axis of an abrasive ridge in the second group.

In yet another embodiment of the abrasive article of the present invention, each abrasive ridge has a distal end spaced from the surface and each distal end extends to a third imaginary plane which is spaced from and parallel to the surface. For example, in one embodiment, the abrasive composites have the same height value measured from the surface to distal end in a range of from about 50 micrometers and about 1020 micrometers.

In another preferred embodiment of the abrasive article of the invention, abrasive composites are fixed on the major surface in a density of about 100 to about 10,000 abrasive composites/cm^2. In one further embodiment, substantially the entire surface area of the major surface is covered by the abrasive composites.

In another embodiment of the invention relating to a method for making an abrasive article described herein, a method comprises the steps of:

(a) preparing an abrasive slurry wherein the abrasive slurry comprises a plurality of abrasive particles dispersed in a binder precursor;

(b) providing a backing having a front surface and a back surface; and a production tool provided with a plurality of cavities in at least one major surface thereof, each cavity having a precise shape defined by a distinct and discernible boundary which includes specific dimensions, wherein the precise cavity shapes are not all identical;

(c) providing a means to apply the abrasive slurry into a plurality of the cavities of the production tool;

(d) contacting the front surface of the backing with the production tool such that the abrasive slurry wets the front surface;

(e) solidifying the binder precursor to form a binder, whereupon solidification the abrasive slurry is converted into a plurality of abrasive composites; and

(f) separating the production tool from the backing after the solidifying to provide a plurality of abrasive composites as attached to the backing each having a precise shape defined by a distinct and discernable boundary which include specific dimensions, wherein the precise abrasive composite shapes are not all identical.

It is preferred that the six steps are carried out in a continuous manner, thereby providing an efficient method of making a coated abrasive article.

Alternatively, this method can be practiced where the abrasive slurry can be applied to the backing instead of the production tool before contacting of the coated backing with the cavitated side of the production tool to fill the cavities in same.

In still another embodiment, the abrasive composite described herein is used in a method to reduce the surface of a workpiece, having the steps of:

(a) bringing into frictional contact a workpiece surface and the above-described abrasive article; and

(b) moving at least one of said abrasive article or said workpiece surface relative to the other such that the surface finish of said workpiece surface is reduced.

In yet another embodiment, the invention relates to a production tool for making the aforesaid abrasive article, which comprises a sheet-like structure having a plurality of cavities formed on a major surface thereof, each cavity having a precise shape defined by a distinct and discernible boundary which includes specific dimensions, wherein the precise cavity shapes are not all identical.

In another embodiment of the invention, there is a method of making a master, and the product of this method, which can be used to form the aforesaid production tool, said master having a major surface extending within a first imaginary plane, comprising the steps of:

(1) determining angles corresponding to facing right and left planar surfaces of adjacent three-dimensional shapes and wherein each of said angles has a value as measured between its planar surface and a plane which extends in a normal direction to said master surface and contains an edge of said planar surface in contact with said surface, by the following substeps:

(i) selecting an angle value between, but not including, 0° and 90° to establish a first right half angle of a first right planar surface of a first right-side three-dimensional shape with a random number generating means capable of randomly selecting an angle value between, but not including, 0° and 90°;

(ii) selecting an angle value between, but not including, 0° and 90° with said random number generating means to establish a first left half angle for a first left planar surface of a first left-side three-dimensional shape facing said first right planar surface of said first right-side three-dimensional shape;

(iii) proceeding along a first direction extending linearly within said first imaginary plane to a second left planar surface of a second left-side three-dimensional shape located adjacent said first left-side three-dimensional shape and using said random number generating means to select a value between, but not including, 0° and 90° to establish a second left planar angle for said second left planar surface;

(iv) using said random number generating means to select a value between, but not including, 0° and 90° for a second right planar surface of a second right-side three-dimensional shape facing said second left planar surface;

(v) proceeding along said first direction to a third right-side three-dimensional shape located adjacent said second right-side three-dimensional shape;

(vi) repeating said substeps (i), (ii), (iii), (iv), and (v), in that sequence, at least once;

(2) repeating step (1) except that the angles are determined for left and right planar surfaces of adjacent three-dimensional shapes deployed in two adjacent rows in a second direction extending linearly within said first imaginary plane, wherein said first and second directions intersect;

(3) using means to determine, for a given width of said surface of said master, locations of grooves required to be cut by a cutting means to form a series of intersecting grooves defining a plurality of precise three-dimensional shapes having said angles calculated by steps (1) and (2); and

(4) providing a cutting means to cut grooves in said surface of said master in correspondence to said angles calculated by steps (1) and (2) and said groove locations determined by step (3) to form a series of intersecting grooves which define a plurality of

precise three-dimensional shapes upraised from said surface, each of said precise shapes being defined by a distinct and discernible boundary including specific dimensions, wherein not all said three-dimensional shapes are identical. This master can then be used to form the aforsaid production tool such as by applying a molten polymer onto the master surface, solidifying the polymer and removing the production tool having a surface containing cavities having shapes in counter-correspondence to the projections on the master surface.

Preferably, in this aspect of the invention, the right and left half angles of the projections formed in the master surface each have a value between 8° and 45° and the three-dimensional shapes comprise pyramids.

Other features, advantages, and constructs of the invention will be better understood from the following description of figures and the preferred embodiments of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an end sectional view representing one embodiment of an abrasive article of this invention.

Fig. 2 is an end sectional view representing another embodiment of an abrasive article of this invention.

Fig. 3 is a side schematic view showing an apparatus for making an abrasive article according to this invention.

Fig. 4 is a side schematic view showing an alternate apparatus for making an abrasive article according to this invention.

Fig. 5 is a Scanning Electron Microscope (SEM) photomicrograph taken at 45X of the top surface of an abrasive article of the invention having 355 micrometer high pyramidal-shaped abrasive composites of varying dimension.

Fig. 6 is a SEM photomicrograph taken at 25X of the top surface of a polypropylene production tool of the present invention having about 355 micrometer deep pyramidal-shaped cavities of varying dimensions.

Fig. 7 is a plane view in schematic of a production tool of the invention.

Fig. 8 is a schematic plane view of the topography of an abrasive article of the present invention having pyramidal shapes for all the abrasive composites, wherein adjacent shapes have the same height but different side angles.

DETAILED DESCRIPTION

The abrasive article of the invention exhibits a high rate of cut while imparting a relatively level, fine surface finish on the workpiece being abraded and does not readily scribe the workpiece. While not desiring to be bound to any theory at this time, it is hypothesized that an array of abrasive composites having perfect pitch, i.e., an array of abrasive composites that are all identical in dimensions, may generate a vibrational resonance, whereby the working abrasive article surface may reach a resonant vibration state which can cause surface finish problems, known as chatter marks. In the present invention, it is believed that the variation in the dimensions between adjacent precisely-shaped abrasive composites disrupts and/or prevents such vibrational resonance from developing to thus provide a high cut-rate, fine finish with decreased chatter incidence in addition to decreased scribing.

For purposes of this invention, the expression "precisely-shaped", or the like, as used herein in describing the abrasive composites, refers to abrasive composites having a shape that has been formed by curing the curable binder of a flowable mixture of abrasive particles and curable binder while the mixture

is both being borne on a backing and filling a cavity on the surface of a production tool. Such a "precisly shaped" abrasive composite would thus have precisely the same shape as that of the cavity. Further, the precise shape of the abrasive composite is defined by relatively smooth-surfaced sides that are bounded and joined by well-defined sharp edges having distinct edge lengths with distinct endpoints defined by the intersections of the various sides with the proviso that at least one of said abrasive composites has at least one dimension which is different from that of an adjacent abrasive composite or composites.

For purposes of this invention, the term "boundary", as used herein to define the abrasive composites, means the exposed surfaces and edges of each abrasive composite that delimit and define the actual three-dimensional shape of each abrasive composite. These distinct and discernible boundaries are readily visible and clear when a cross-section of the abrasive article of the invention is examined under a microscope such as a scanning electron microscope. The distinct and discernible boundaries of each abrasive composite form the cross-sectional outlines and contours of the precise shapes of the present invention. These boundaries separate and distinguish one abrasive composite from another even when the abrasive composites abutt each other along a common border at their bases. By comparison, in an abrasive composite that does not have a precise shape, the boundaries and edges are not definitive, e.g., where the abrasive composite sags before completion of its curing.

For purposes of this invention, the term "dimension", as used in connection with defining the abrasive composites, means a measure of spatial extent such as an edge length of a side surface (inclusive of

the base) of the shape associated with an abrasive composite or, alternatively, the "dimension" can mean a measure of an angle of inclination of a side surface extending from the backing. Therefore, for purposes of this invention, a "dimension" that is "different" for two different abrasive composites, means an edge length or an angle of intersection made at the meeting edge of two planar surfaces of a shape of a first abrasive composite that is nowhere duplicated in value by any of the edge lengths or angles of intersections defining the shape of a second abrasive composite in the array. These first and second abrasive composites can be adjacent in a preferred embodiment.

For purposes of this invention, the terminology "geometrical shape" means a basic category of three-dimensional regular geometrical shape, such as cubic, pyramidal, pyrismatic, conical, cylindrical, truncated pyramidal, truncated conical and the like.

For purposes of this invention, the terminology "adjacent composite" or "adjacent composites", or the like, as used herein, means at least two neighboring composites which lack any intervening abrasive composite structure located on a direct line therebetween.

Referring to Figure 1 for illustrative purposes, the side view of the abrasive article 10 shows a backing 11 having a pair of opposite side edges 19 (one shown), a machine direction axis (not shown) would extend parallel to the direction of said side edges 19 for purposes of this illustration, and a plurality of abrasive composites 12 fixed to at least the top surface 16 of the backing. The abrasive composites 12 comprise a plurality of abrasive particles 13 dispersed in the binder 14. Each abrasive composite has a discernible precise shape. It is preferred that the abrasive particles do not protrude beyond the planar

surface planes 15 of the shape before the coated abrasive article is put into service. As the coated abrasive article is being used to abrade a surface, the composite breaks down revealing unused abrasive particles.

In one aspect of the invention, viz., where the abrasive composites are spaced-apart at constant pitch (constant peak- to-peak distance from centers of adjacent abrasive composites), the "adjacent composite" will involve one nearest neighboring composite or multiple nearest neighboring composites equidistantly spaced from the abrasive composite which has the different dimension thereto. However, in another aspect of the invention, if the abrasive composites are spaced at a varied pitch, then it is possible, in that instance, for the "adjacent composite" to involve an abrasive composite which is not necessarily the closest composite as spaced from the abrasive composite having the different dimension thereto, as long as no intervening abrasive structure is located on a direct line therebetween.

<u>Backing</u>

A backing can be conveniently used in this invention to provide a surface for deploying the abrasive composites thereon, wherein such a backing has a front and back surface and can be any conventional abrasive backing. Examples of such include polymeric film, primed polymeric film, cloth, paper, vulcanized fiber, nonwovens, and combinations thereof. The backing optionally may be a reinforced thermoplastic backing, such as described in the assignee's co-pending United States application No. 07/811,547 (Stout et al., filed 20 December 1991) or an endless belt as described in the assignee's co-pending U.S. application No. 07/919,541 (Benedict et al., filed 20 December 1991). The backing may also contain a treatment or treatments

to seal the backing and/or modify some physical properties of the backing. These treatments are well known in the art.

The backing may also have an attachment means on its back surface to secure the resulting coated abrasive to a support pad or back-up pad. This attachment means can be a pressure sensitive adhesive or a loop fabric for a hook and loop attachment. Alternatively, there may be a intermeshing attachment system, such as described in the U.S. Patent No. 5,201,101 (Rouser et al.).

The back side of the abrasive article may also contain a slip resistant or frictional coating. An example of such a coating include compositions containing an inorganic particulate (e.g., calcium carbonate or quartz) dispersed in an adhesive. An antistatic coating comprising materials such as carbon black or vanadium oxide also may be included in the abrasive article, if desired.

Abrasive Composite

a. Abrasive Particles

The abrasive particles typically have a particle size ranging from about 0.1 to 1500 micrometers, usually between about 0.1 to 400 micrometers, preferably between 0.1 to 100 micrometers and more preferably between 0.1 to 50 micrometers. It is preferred that the abrasive particles have a Mohs' hardness of at least about 8, more preferably above 9. Examples of such abrasive particles include fused aluminum oxide (which includes brown aluminum oxide, heat treated aluminum oxide, and white aluminum oxide), ceramic aluminum oxide, green silicon carbide, silicon carbide, chromia, alumina zirconia, diamond, iron oxide, ceria, cubic boron nitride, boron carbide, garnet, and combinations thereof.

The term abrasive particles also encompasses when single abrasive particles are bonded together to form an abrasive agglomerate. Suitable abrasive agglomerates for this invention are further described in U.S. Patent Nos. 4,311,489 (Kressner); 4,652,275 (Bloecher et al.) and 4,799,939 (Bloecher et al.).

It is also within the scope of this invention to have a surface coating on the abrasive particles. The surface coating may have many different functions. In some instances the surface coatings increase adhesion to the binder, alter the abrading characteristics of the abrasive particle, and the like. Examples of surface coatings include coupling agents, halide salts, metal oxides including silica, refractory metal nitrides, refractory metal carbides, and the like.

In the abrasive composite there may also be diluent particles. The particle size of these diluent particles may be on the same order of magnitude as the abrasive particles. Examples of such diluent particles include gypsum, marble, limestone, flint, silica, glass bubbles, glass beads, aluminum silicate, and the like.

b. Binder

The abrasive particles are dispersed in an organic binder to form the abrasive composite. The organic binder can be a thermoplastic binder, however, it is preferably a thermosetting binder. The binder is formed from a binder precursor. During the manufacture of the abrasive article, the thermosetting binder precursor is exposed to an energy source which aids in the initiation of the polymerization or curing process. Examples of energy sources include thermal energy and radiation energy which includes electron beam, ultraviolet light, and visible light. After this polymerization process, the binder precursor is converted into a solidified binder. Alternatively for a thermoplastic binder precursor, during the

manufacture of the abrasive article the thermoplastic binder precursor is cooled to a degree that results in solidification of the binder precursor. Upon solidification of the binder precursor, the abrasive composite is formed.

The binder in the abrasive composite is generally also responsible for adhering the abrasive composite to the front surface of the backing. However, it some instances there may be an additional adhesive layer between the front surface of the backing and the abrasive composite.

There are two main classes of thermosetting resins, condensation curable and addition polymerized resins. The preferred binder precursors are addition polymerized resin because they are readily cured by exposure to radiation energy. Addition polymerized resins can polymerize through a cationic mechanism or a free radical mechanism. Depending upon the energy source that is utilized and the binder precursor chemistry, a curing agent, initiator, or catalyst is sometimes preferred to help initiate the polymerization.

Examples of typical binders precursors include phenolic resins, urea-formaldehyde resins, melamine formaldehyde resins, acrylated urethanes, acrylated epoxies, ethylenically unsaturated compounds, aminoplast derivatives having pendant unsaturated carbonyl groups, isocyanurate derivatives having at least one pendant acrylate group, isocyanate derivatives having at least one pendant acrylate group, vinyl ethers, epoxy resins, and mixtures and combinations thereof. The term acrylate encompasses acrylates and methacrylates.

Phenolic resins are widely used in abrasive article binders because of their thermal properties, availability, and cost. There are two types of

phenolic resins, resole and novolac. Resole phenolic resins have a molar ratio of formaldehyde to phenol greater than or equal to one to one, typically between 1.5:1.0 to 3.0:1.0. Novolac resins have a molar ratio of formaldehyde to phenol of less than one to one. Examples of commercially available phenolic resins include those known by the tradenames "Durez" and "Varcum" from Occidental Chemicals Corp.; "Resinox" from Monsanto; "Aerofene" from Ashland Chemical Co. and "Aerotap" from Ashland Chemical Co.

Acrylated urethanes are diacrylate esters of hydroxy terminated NCO extended polyesters or polyethers. Examples of commercially available acrylated urethanes include UVITHANE 782, available from Morton Thiokol Chemical, and CMD 6600, CMD 8400, and CMD 8805, available from Radcure Specialties.

Acrylated epoxies are diacrylate esters of epoxy resins, such as the diacrylate esters of bisphenol A epoxy resin. Examples of commercially available acrylated epoxies include CMD 3500, CMD 3600, and CMD 3700, available from Radcure Specialities.

Ethylenically unsaturated resins include both monomeric and polymeric compounds that contain atoms of carbon, hydrogen, and oxygen, and optionally, nitrogen and the halogens. Oxygen or nitrogen atoms or both are generally present in ether, ester, urethane, amide, and urea groups. Ethylenically unsaturated compounds preferably have a molecular weight of less than about 4,000 and are preferably esters made from the reaction of compounds containing aliphatic monohydroxy groups or aliphatic polyhydroxy groups and unsaturated carboxylic acids, such as acrylic acid, methacrylic acid, itaconic acid, crotonic acid, isocrotonic acid, maleic acid, and the like. Representative examples of acrylate resins include methyl methacrylate, ethyl methacrylate styrene, divinylbenzene, vinyl toluene, ethylene glycol

diacrylate, ethylene glycol methacrylate, hexanediol diacrylate, triethylene glycol diacrylate, trimethylolpropane triacrylate, glycerol triacrylate, pentaerythritol triacrylate, pentaerythritol methacrylate, pentaerythritol tetraacrylate and pentaerythritol tetraacrylate. Other ethylenically unsaturated resins include monoallyl, polyallyl, and polymethallyl esters and amides of carboxylic acids, such as diallyl phthalate, diallyl adipate, and N,N-diallyladipamide. Still other nitrogen containing compounds include tris(2-acryloyl oxyethyl)isocyanurate, 1,3,5-tri(2-methyacryloxyethyl)- s-triazine, acrylamide, methylacrylamide, N-methylacrylamide, N,N-dimethylacrylamide, N-vinylpyrrolidone, and N-vinylpiperidone.

The aminoplast resins have at least one pendant alpha, beta-unsaturated carbonyl group per molecule or oligomer. These unsaturated carbonyl groups can be acrylate, methacrylate, or acrylamide type groups. Examples of such materials include N-hydroxymethyl)-acrylamide, N,N'-oxydimethylene-bisacrylamide, ortho and para acrylamidomethylated phenol, acrylamidomethylated phenolic novolac, and combinations thereof. Examples of these materials are further described in U.S. Patent No. 4,903,440 (Larson et al.) and U.S. Patent No. 5,236,472 (Kirk et al.).

Isocyanurate derivatives having at least one pendant acrylate group and isocyanate derivatives having at least one pendant acrylate group are further described in U.S. Patent 4,652,274 (Boettcher et al.). The preferred isocyanurate material is a triacrylate of tris(hydroxy ethyl) isocyanurate.

Epoxy resins have an oxirane and are polymerized by the ring opening. Such epoxide resins include monomeric epoxy resins and oligomeric epoxy resins. Examples of some preferred epoxy resins include

2,2-bis[4- (2,3-epoxypropoxy)-phenyl propane] (diglycidyl ether of bisphenol A) and commercially available materials under the trade designation "Epon 828", "Epon 1004", and "Epon 1001F" available from Shell Chemical Co., "DER-331", "DER-332", and "DER-334" available from Dow Chemical Co. Other suitable epoxy resins include glycidyl ethers of phenol formaldehyde novolac (e.g., "DEN-431" and "DEN-428" available from Dow Chemical Co.).

The epoxy resins of the invention can polymerize via a cationic mechanism with the addition of an appropriate cationic curing agent. Cationic curing agents generate an acid source to initiate the polymerization of an epoxy resin. These cationic curing agents can include a salt having an onium cation and a halogen containing a complex anion of a metal or metalloid. Other cationic curing agents include a salt having an organometallic complex cation and a halogen containing complex anion of a metal or metalloid which are further described in U.S. Patent 4,751,138 (Tumey et al.)(column 6, line 65 to column 9, line 45). Another example is an organometallic salt and an onium salt is described in U.S. Patent 4,985,340 (Palazzotto) (column 4 line 65 to column 14 line 50); European Patent Applications 306,161 and 306,162. Still other cationic curing agents include an ionic salt of an organometallic complex in which the metal is selected from the elements of Periodic Group IVB, VB, VIB, VIIB and VIIIB which is described in European Patent Applications 109,851.

Regarding free radical curable resins, in some instances it is preferred that the abrasive slurry further comprise a free radical curing agent. However in the case of an electron beam energy source, the curing agent is not always required because the electron beam itself generates free radicals.

Examples of free radical thermal initiators include peroxides, e.g., benzoyl peroxide, azo compounds, benzophenones, and quinones. For either ultraviolet or visible light energy source, this curing agent is sometimes referred to as a photoinitiator. Examples of initiators, that when exposed to ultraviolet light generate a free radical source, include but are not limited to those selected from the group consisting of organic peroxides, azo compounds, quinones, benzophenones, nitroso compounds, acryl halides, hydrozones, mercapto compounds, pyrylium compounds, triacrylimidazoles, bisimidazoles, chloroalkytriazines, benzoin ethers, benzil ketals, thioxanthones, and acetophenone derivatives, and mixtures thereof. Examples of initiators that when exposed to visible radiation generate a free radical source, can be found in U.S. Patent No. 4,735,632 (Oxman et al.), entitled Coated Abrasive Binder Containing Ternary Photoinitiator System. The preferred initiator for use with visible light is "Irgacure 369" commercially available from Ciba Geigy Corporation.

The weight ratios between the abrasive particles and binder can range between 5 to 95 parts abrasive particles to 5 to 95 parts binder; more typically, 50 to 90 parts abrasive particles and 10 to 50 parts binder.

c. Additives

The abrasive slurry can further comprise optional additives, such as, for example, fillers (including grinding aids), fibers, lubricants, wetting agents, thixotropic materials, surfactants, pigments, dyes, antistatic agents, coupling agents, plasticizers, and suspending agents. The amounts of these materials are selected to provide the properties desired. The use of these can affect the erodability of the abrasive

composite. In some instances an additive is purposely added to make the abrasive composite more erodable, thereby expelling dulled abrasive particles and exposing new abrasive particles.

Examples of useful fillers for this invention include: metal carbonates (such as calcium carbonate {such as chalk, calcite, marl, travertine, marble and limestone}, calcium magnesium carbonate, sodium carbonate, magnesium carbonate), silica {such as quartz, glass beads, glass bubbles and glass fibers} silicates {such as talc, clays, montmorillonite, feldspar, mica, calcium silicate, calcium metasilicate, sodium aluminosilicate, sodium silicate}, metal sulfates {such as calcium sulfate, barium sulfate, sodium sulfate, aluminum sodium sulfate, aluminum sulfate}, gypsum, vermiculite, wood flour, aluminum trihydrate, carbon black, metal oxides {such as calcium oxide or lime, aluminum oxide, titanium oxide}, and metal sulfites {such as calcium sulfite}.

The term filler also encompasses materials that are known in the abrasive industry as grinding aids. A grinding aid is defined as particulate material that the addition of which has a significant effect on the chemical and physical processes of abrading which results in improved performance. Examples of chemical groups of grinding aids include waxes, organic halide compounds, halide salts and metals and their alloys. The organic halide compounds will typically break down during abrading and release a halogen acid or a gaseous halide compound. Examples of such materials include chlorinated waxes like tetrachloronaphtalene, pentachloronaphthalene; and polyvinyl chloride. Examples of halide salts include sodium chloride, potassium cryolite, sodium cryolite, ammonium cryolite, potassium tetrafluoroboate, sodium tetrafluoroborate, silicon fluorides, potassium chloride, magnesium

chloride. Examples of metals include, tin, lead, bismuth, cobalt, antimony, cadmium, iron, and titanium. Other miscellaneous grinding aids include sulfur, organic sulfur compounds, graphite, and metallic sulfides.

Examples of antistatic agents include graphite, carbon black, vanadium oxide, humectants, and the like. These antistatic agents are disclosed in U.S. Patent Nos. 5,061,294 (Harmer et al.); 5,137,542 (Buchanan et al.), and 5,203,884 (Buchanan et al.).

A coupling agent can provide an association bridge between the binder precursor and the filler particles or abrasive particles. Examples of coupling agents include silanes, titanates, and zircoaluminates. The abrasive slurry preferably contains anywhere from about 0.01 to 3% by weight coupling agent.

An example of a suspending agent is an amorphous silica particle having a surface area less than 150 meters square/gram that is commercially available from DeGussa Corp., under the trade name "OX-50".

Abrasive Composite Shape

Each abrasive composite has a precise shape associated with it. The precise shape is delimited by a distinct and discernible boundary, these terms being defined hereinabove. These distinct and discernible boundaries are readily visible and clear when a cross-section of the abrasive article of the invention is examined under a microscope such as a scanning electron microscope, e.g., as shown in Figure 5. The distinct and discernible boundaries of each abrasive composite form the outline or contour of the precise shapes of the present invention. These boundaries separate and distinguish one abrasive composite from another even when the abrasive composites abutt each other along a common border at their bases.

In comparison, in an abrasive composite that does not have a precise shape, the boundaries and edges are not definitive, e.g., where the abrasive composite sags before completion of its curing. Thus, the expression "precisely-shaped", or the like, as used herein in describing the abrasive composites, also refers to abrasive composites having a shape that has been formed by curing the curable binder of a flowable mixture of abrasive particles and curable binder while the mixture is both being borne on a backing and filling a cavity on the surface of a production tool. Such a precisly shaped abrasive composite would thus have precisely the same shape as that of the cavity. These cavities in a production tool are depicted in Figure 6.

A plurality of such composites provide three-dimensional shapes that project outward from the surface of the backing in an inverse pattern to that presented by the production tool. Each composite is defined by a well-defined boundary or perimeter, the base portion of the boundary being the interface with the backing to which the precisely shaped composite is adhered. The remaining portion of the boundary is defined as the inverse shape of the cavity in the surface of the production tool in which the composite is cured. The entire outer surface of the composite is confined, either by the backing or by the cavity, during its formation. Suitable methods and techniques for forming precisely-shaped composites are disclosed in U.S. Patent No. 5,152,917 (Pieper et al.).

This invention departs from U.S. Patent No. 5,152,917 (Pieper et al.), however, insofar as the provision of differing dimensioned shapes, among other things, in the array of abrasive composites. This proviso can be established by any convenient approach, e.g., by arbitrarily assigning at least one dimensional variance, such as defined hereinbelow, between adjacent

composite shapes in a portion or the whole of the array of composites for an abrasive article. An array of grooves can be formed in a surface of a master tool, e.g., by use of a diamond turning machine, from which is produced a production tool having an array of cavity shapes, which, in turn, can receive and mold an abrasive slurry described herein, which are the inverse shape of the predetermined array of abrasive composite shapes. Alternatively, as described herein, a copy of a desired pattern of variably dimensioned shapes of abrasive composites can be formed in the surface of a so-called metal master, e.g., aluminum, copper, bronze, or a plastic master such as acrylic plastic, either of which can be nickel-plated after grooving, as by diamond turning grooves to leave upraised portions corresponding to the desired predetermined shapes of the abrasive composites. Then, flexible plastic production tooling can be formed, in general, from the master by a method explained in U.S. Patent No. 5,152,917 (Pieper et al). As a result, the plastic production tooling has a surface which includes indentations having the inverse shape of the abrasive composites to be formed therewith. Alternatively, the metal master can be manufactured by diamond turning grooves to leave the desired shapes in a metal surface which is amenable to diamond turning, such as aluminum, copper or bronze, and then nickel plating the grooved surface to provide the metal master. Exemplary techniques for making the varying dimensioned abrasive composites will be described in greater detail hereinbelow.

Regarding the construction of the abrasive composites per se, referring to Figure 1 for illustrative purposes, the abrasive composite 12 has a boundary 15. The boundary or boundaries associated with the shape result in one abrasive composite being

physically separated to some extent from another adjacent abrasive composite. To form an individual abrasive composite, a portion of the boundaries forming the shape of the abrasive composite must be separated from one another. Note that in Figure 1, the base or a portion of the abrasive composite closest to the backing can abutt with an adjacent abrasive composite. Referring to Figure 2, the abrasive article 20 of the invention comprises a backing 21 having a plurality of abrasive composites 22 bonded to the backing. The abrasive composites comprises a plurality of abrasive particles 23 that are dispersed in a binder 24. In this aspect of the invention, there are open spaces 25 between adjacent composites. It is also within the scope of this invention to have a combination of abrasive composites bonded to a backing in which some of adjacent abrasive composites abutt, while other adjacent abrasive composites have open spaces between them.

In some instances, e.g., pyramidal non-cylindrical shapes, the boundaries forming the sides of the shape also are planar. For such shapes that have multiple planes, there are at least four planes (inclusive of three sides and the bottom or base). The number of planes for a given shape can vary depending upon the desired geometry, for instance the number of planes can range from four to over 20. Generally, there are between four to ten planes, preferably between four to six planes. These planes intersect to form the desired shape and the angles at which these planes intersect will determine the shape dimensions. Referring to Figure 1, the abrasive composite 12 has a boundary 15 which is planar. The side planes 15A and 15b intersect at an angle γ, with cross-section 15C facing the viewer and is coplanar with the page.

A key aspect of this invention is that at least one the abrasive composites has a different dimension from another abrasive composite in the array. Preferably, the different dimension is established between at least one pair of adjacent composites, and even more preferably, established for each and every pair of adjacent composites provided on the surface of the abrasive article. The terminology of "every pair" of adjacent composites encompasses an arbitrary consideration of every composite on the surface of the abrasive article as paired with its adjacent composite. In general, at least 10% of the pairs of adjacent composites have a different dimension therebetween, preferably at least 30%, more preferably at least 50%. Most preferably, substantially 100% of the abrasive composites have a different dimension from its respective paired adjacent abrasive composite. The result of this proviso of different dimensions between abrasive composites, viz. between adjacent pairs of abrasive composites, results in an abrasive article that produces a relatively finer surface finish on the workpiece being abraded or refined. Since the dimensions of adjacent abrasive composites vary, there is a reduced tendency for scribed grooves to be imparted by the precisely abrasive composites into the workpiece surface. In general, if less than 10% of the pairs of abrasive composites have an adjacent composite that has a different dimension, the effect of the invention of decreasing scribing while achieving high-cut rates and fine finishes may not be satisfactorily realized. In general, the number of pairs of adjacent abrasive composites that have different dimensions is selected to minimize or reduce scribing. The percentage of the total abrasive composites that this number of pairs represents will depend upon several factors such as the workpiece type, abrading interface pressure,

abrasive article rotation speed and other typical abrading conditions.

It is within the scope of this invention to have some, but never all, of the abrasive composites present on the surface which have identical shapes. However, the abrasive composites having identical shapes, if present, preferably should not be located directly adjacent to or next to one another in order to fully realize the benefits of the invention. For instance, two abrasive composites in the abrasive article may have shapes defined by same dimensions, but, preferably, the two abrasive composites should be separated from one another in the array of composites by at least one intervening abrasive composite that differs in a dimension from each.

There must be at least one dimension associated with at least one of the abrasive composites that is different from another abrasive composite. However, it also is within the scope of this invention that there are two or more different dimensions therebetween. These dimensions can be varied in a variety of ways, such as by providing a different length of an edge at the intersection of two planar surfaces of a shape of a composite; by providing a different angle formed at the meeting edge of two adjacent planar surfaces of a shape of a composite; or by providing different types of geometrical shapes for the abrasive composites to provide either a different edge length and/or a different angle.

If an edge length is varied to provide the different dimension for purposes of the invention, in one embodiment, the length or dimensions of the edges in composites, particularly adjacent composites, each having a pyramidal shape as the geometrical shape and a common height of between 25 and 1020 micrometers, generally can differ from at least about 1 to about 500

micrometers, and more preferably between 5 to 250 micrometers. In one embodiment, the length of the at least one edge of a first composite in the array has a length which varies with respect to the length of any edge of a second composite in a ratio between 10:1 to 1:10, not inclusive of 1:1, and preferably as between two adjacent composites.

More generally, the abrasive composite shape of this invention can be any convenient shape, but it is preferably a three-dimensional regular geometric shape such as a cubic, prismatic (e.g., triangular, quadrilateral, hexagonal, etc.), conical, truncated conical (flat top), cylindrical, pyramidal, truncated pyramidal (flat top) and the like. The geometrical shape of adjacent abrasive composites can be varied, e.g. pyramidal next to prismatic, in order to provide the requisite dimensional variance therebetween. In one embodiment of the invention, the shapes of the abrasive composites, e.g., pyramidal, all are provided with the same total height value, measured from the backing, in a range of from about 50 micrometers to about 1020 micrometers.

A preferred geometrical shape is a pyramid and the pyramid can be a four or five side sided (inclusive of the base) pyramid. In one preferred embodiment, all composite shapes are pyramidal. Even more preferably, the dimensional variance is achieved between adjacent pyramidal-shaped composites by varying the angle formed by a side surface with the backing in adjacent pyramids. For example, angles α and β formed by the sides of adjacent pyramidal shaped composites, such as depicted in Figure 1, are different angles from each other and each have a value of between 0° and 90° (i.e. non-inclusive of 0° and 90°). Preferably, the angle α or β formed between a side surface of the pyramidal-shaped composites and an imaginary plane 17 (Figure 1)

extending normal to the intersection of the respective side surface and the backing should be greater than or equal to 8°, but less than or equal to 45°. From a practical standpoint, angles less than 8° may release cured composite shapes from the production tool with greater difficulty. On the other hand, angles greater than 45° may unduly enlarge the spacing between adjacent abrasive composites such that insufficient abrading surfaces are provided over the area of the backing.

It also is preferable to select angles for α and β wherein each have a value between 0° and 90° and which differ in magnitude by at least about 1°, and more preferably at least about 5°.

It is also preferred to form pyramidal shapes for the abrasive composites where two side surfaces of each pyramid meet at the apex of each pyramid to form a material-included angle γ (see Figure 1) in a cross-sectional view of the pyramid having a value of greater than or equal to 25° and less than or equal to 90°. The lower value of 25° may be a practical limit since it can be difficult to form a peak or apex shape for an abrasive composite which is sharp and less than 25° with the slurry and production tool methodology described herein. To more fully realize the benefits of the invention, this proviso with respect to material-included angle γ should be used together with the above-mentioned proviso that intervening angles α and β between adjacent composites be provided as different and randomly selected between 0° and 90° as explained hereinabove.

Further, in any individual abrasive composite, the angles made by the various surface planes with the backing do not necessarily have to be the same for a given composite. For instance in a four sided pyramid (one base and three side surfaces), the angles formed

by any of the first, second and third side planes with the backing can be different from each other. Naturally, the angle at which the side surfaces intersect with each other will also vary as the angle formed between the side surface and the backing are varied.

Also, in the embodiment of this invention where the dimensional variance between adjacent composites is established by varying side surface angles between adjacent abrasive composites, such as angles α and β (Figure 1), it is preferred that the respective angles chosen for each of α and β between adjacent composites are not repeated and constant throughout the array of abrasive composites, which is believed to even further ensure no resonance is created between the workpiece and the abrasive article. Therefore, it is more desirable to permit and provide different values for each of α and β between 0° and 90° as one proceeds from one pair adjacent composites to the next immediate pair of adjacent composites along either the widthwise or lengthwise direction of the abrasive article (e.g., see Figure 8). This change in the values of α and β between different sets of adjacent composites in the array can be effected in any convenient manner, such as by randomly picking the values for each of α and β between the range 0 and 90 degrees.

For example, if α, as the right half angle (Figure 1), can be randomly selected in the range of between 0° and 90° for an abrasive composite in one row of composites, then β, as the left half angle facing α, is randomly chosen for the adjacent abrasive composite in the adjacent row of composites; and then, as one preceeds to the next pair of adjacent abrasive composites in either the widthwise or lengthwise direction along the rows of composites in the array, a new β, as left half angle, is randomly selected between

0° and 90° degrees and then a new value for α, as the facing right half angle, of the adjacent composite can be randomly selected in the range of 0° to 90° degrees, and so forth throughout the array. This practice is desirable in order to provide a more uniform distribution of angles between 0° and 90° degrees throughout the array of abrasive composites in the article.

The actual selection of the angles α and β, and γ, throughout the array of abrasive composites, randomly and subject to the preferred constraints described herein, can be accomplished in any convenient manner, for example, by systematic random selections of angle values by draw within the preferred numerical constraint mentioned herein. These systematic selections for an array, can be facilitated and expedited by using a common computer, e.g. a desktop computer, using the angle constraints described herein to delimit the range of angle values from which the computer makes a random choice. Algorithms for selection of random numbers are generally known in the statistical and computer fields, and have been adapted to this aspect of the invention. For instance, the well known linear congruential method for generating pseudorandom numbers can be applied towards randomly selecting the angles α and β. The application and implementation of random number generation for selecting angles for the side faces of the abrasive composite shapes in the present application is exemplified in the computer source code described in the APPENDIX hereinafter.

In any event, the angle values, once so selected for the abrasive composites in the array, can be used to determine and predicate the pattern and shapes of indentations formed by a diamond turning machine in the surface of a metal production tool or production tool,

which, in turn, can be used to make the abrasive composite articles of the invention by methods described herein.

In some instances it is preferred to have the height and geometrical shape of all the composites as the same. This height is the distance of the abrasive composite from the backing to its outermost point before the abrasive article is used. If the height and shape are constant, it is then preferred to have the angle between planes vary.

In order to achieve a fine surface finish on the workpiece, it is also preferred that the peaks of the abrasive composites do not align in a column which is parallel to the abrading direction performed in the machine direction. If the abrasive composite peaks align in a column parallel to the abrading direction, this tends to result in grooves imparted to the workpiece and a coarser surface finish. Thus, it is preferred that the abrasive composites be offset from one another to prevent this alignment.

In general there are at least 5 individual abrasive composites per square centimeter. In some instances, there may be at least about 100 individual abrasive composites/square centimeter or higher, and more preferably, about 2,000 to 10,000 abrasive composites/square centimeter. There is no operational upper limit on the density of the abrasive composites; although, from a practical standpoint, at some point it may not be possible to increase the cavity density and/or form precisely shaped cavities in the surface of the production tooling preferably used to make the array of abrasive composites. In general, this number of abrasive composites result in an abrasive article that has a relatively high rate of cut, a long life, but also results in a relatively fine surface finish on the workpiece being abraded. Additionally, with this

number of abrasive composites there is a relatively low unit force per each abrasive composite. In some instances, this can result in better, more consistent, breakdown of the abrasive composite.

Method of Making the Abrasive Article

Although additional details will be described later herein on the methods of making the abrasive article of the invention, in general, the first step in making the abrasive article is to prepare an abrasive slurry. The abrasive slurry is made by combining together by any suitable mixing technique the binder precursor, the abrasive particles, and the optional additives. Examples of mixing techniques include low shear and high shear mixing, with high shear mixing being preferred. Ultrasonic energy may also be utilized in combination with the mixing step to lower the abrasive slurry viscosity. Typically, the abrasive particles are gradually added into the binder precursor. The amount of air bubbles in the abrasive slurry can be minimized by pulling a vacuum during the mixing step, for example, by employing conventional vacuum-assisted methods and equipment.

In some instances it is preferred to heat, generally in the range of 30 to 70°C, the abrasive slurry to lower the viscosity. It is important the abrasive slurry have a rheology that coats well and in which the abrasive particles and other fillers do not settle.

If a thermosetting binder precursor is employed, the energy source can be thermal energy or radiation energy depending upon the binder precursor chemistry. If a thermoplastic binder precursor is employed the thermoplastic is cooled such that it becomes solidified and the abrasive composite is formed. Other more detailed aspects of the method(s) to make the abrasive article of the invention will be described hereinbelow.

Production Tool

A production tool is important, from both practical and technological standpoints, in making an abrasive article of the invention, especially in view of the relatively small sizes of the abrasive composites. The production tool contains a plurality of cavities. These cavities are essentially the inverse shape of the abrasive composite desired and are responsible for generating the shape of the abrasive composites. The dimensions of the cavities are selected to provide the desired shape and dimensions of the abrasive composites. If the shape or dimensions of the cavities are not properly fabricated, the resulting production tool will not provide the desired dimensions for the abrasive composites.

The cavities can be present in a dot like pattern with spaces between adjacent cavities or the cavities can abutt against one another. The cavities butt up against one another to facilitate release of the shaped and cured abrasive slurry. Additionally, the shape of the cavities is selected such that the cross-sectional area of the abrasive composite decreases in the direction away from the backing.

In a more preferred embodiment of the production tool, the production tool has two opposing parallel side edges bounding an array of cavities so configured to provide differing dimensions in the shapes of adjacent abrasive composites formed therewith by methods described herein over a distinct segment of length of the abrasive article, in either a length and/or width direction of the abrasive article, and then this predetermined pattern of differing composite shapes can be repeated at least once more or repeatedly along the length and/or width of the abrasive article, if desired and convenient.

For example, Figure 7 is a top view representation of a production tool 70 that can be used to make an abrasive article of the invention. The side edges 71 of the production tool are parallel to the machine direction (not shown) of the production tool and are perpendicular to the transverse width direction of the production tool. Cavitites 74 are delimited by intersecting upraised portions represented by solid lines 72 and 73. The production tool has six distinct groups A, B, C, D, E and F of cavities, wherein in each group the cavities are aligned in parallel rows bounded by upraised portions 72, wherein the upraised portions 72 and 73 are the nondeformed (noncavitated) remainder of the tooling sheet. These groups A-E are arranged head-to-tail along the length of the tooling, as shown in Figure 7. The rows of cavities in each group that are aligned most closely with side edges 71 trace imaginary lines extending at non-parallel (nonzero) angles to the machine direction of the production tool, and which angles differ from group A to group B to group C, and so forth up to group F. The angles of the rows of cavities (and intervening upraised portions 72) made with the side edges 71 should be established as between 0° to 90°. Scribing problems can arise at either 0° or 90° angles for rows of cavities with the side edges 71. Preferably, angles of 5° to 85° are selected for the angles of the rows of cavities with the machine direction more assuredly avoid scribing problems.

The angles of the rows of cavities preferably alternate between clockwise and counterclockwise directionality from group to group, as shown in Figure 7. The angle formed between rows of cavities and upraised portions 72 and the side edges 71 can be selected to be the same or different in absolute magnitude from set to set.

An abrasive article formed with production tool 70 by methods described herein will have an array of abrasive composites formed in the inverse shape to the surface profile presented by the array of cavities in the production tool, such production tool 70. By arranging rows of cavities at angles in the production tooling by means of arrangements such as exemplified in Figure 7, scribing effects can be minimized in the abrasive article made thereby.

Alternatively, the cavities in the production tool can be arranged to be laterally offset, i.e., nonaligned, from one another in the direction advancing parallel to the side edges of the production tool (nondepicted). That is, this embodiment provides an optional manner of forming an array of abrasive composites and intervening grooves which are not arranged in rows which extend parallel to the the side edges of the abrasive article. Instead, the abrasive composites are staggered from each other and non-aligned when viewed from the front of the abrasive article into the direction parallel to the side edges of the abrasive article.

The production tool can be a belt, a sheet, a continuous sheet or web, a coating roll such as a rotogravure roll, a sleeve mounted on a coating roll, or die. The production tool can be composed of metal, (e.g., nickel), metal alloys (e.g., nickel alloys), plastic (e.g., polypropylene, an acrylic plastic), or any other conveniently formable material. The metal production tool can be fabricated by any conventional technique such as engraving, hobbing, electroforming, diamond turning, and the like.

A thermoplastic production tool can be made by replication off a metal master tool. The metal master will have the inverse pattern desired for the production tool. The metal master can be made with the

same basic techniques useful in directly making the production tool, e.g., by diamond turning a metal surface. In the event of use of a metal master, a thermoplastic sheet material can be heated and optionally along with the metal master such that the thermoplastic material is embossed with the surface pattern presented by the metal master by pressing the two surfaces together. The thermoplastic can also be extruded or cast onto to the metal master and then pressed. The thermoplastic material is cooled to solidify and produce the production tool. Examples of preferred thermoplastic production tool materials include polyester, polycarbonates, polyvinyl chloride, polypropylene, polyethylene and combinations thereof.

Alternatively, a plastic production tool can be directly made, without the need of a master by engraving or diamond turning a predetermined array of cavities, which have the inverse shape of the abrasive composites desired, into a surface of the plastic sheet. If a thermoplastic production tool is utilized, then care must be taken not to generate excessive heat, particularly during the solidifying step, that may distort the thermoplastic production tool. Other suitable methods of production tooling and metal masters are discussed in commonly assigned U.S. Patent Application No. 08/004,929 (Spurgeon et al.), filed 14 December 1993.

For example, a preferred method of making a polymeric production tool of the invention of the type depicted in Figure 7 involves the use of a nickel-plated metal master configured in a drum form. Several flat sections of nickel-plated master, each about 30 centimeters in length, with the varied shapes of indentations corresponding to the shapes desired for the abrasive composites are provided in a surface thereof, are produced by diamond turning with the aid

of a computer directing the cutting action performed by the diamond turning machine. These sections of metal master are welded together head-to-tail, with the grooves of section being at a non-zero angle to the grooves of the next adjacent section. This chain of sections is then fixed to a drum so that the composites are continuous around the circumference of the drum. Care should be taken to minimize any weld seams from distending out from between the sections and at the point of joining. The production tool is cast by extruding polymeric resin onto the drum and passing the extrudant between a nip roll and the drum, and then cooling the extrudant to form a production tool in sheet form having an array of cavities formed on the surface thereof in inverse correspondence to the surface indentations presented by the master on the drum. This process can be conducted continuously to produce a polymeric tool of any desired length.

Energy Sources

When the abrasive slurry comprises a thermosetting binder precursor, the binder precursor is cured or polymerized. This polymerization is generally initiated upon exposure to an energy source. Examples of energy sources include thermal energy and radiation energy. The amount of energy depends upon several factors such as the binder precursor chemistry, the dimensions of the abrasive slurry, the amount and type of abrasive particles and the amount and type of the optional additives. For thermal energy, the temperature can range from about 30 to 150°C, generally between 40 to 120°C. The time can range from about 5 minutes to over 24 hours. The radiation energy sources include electron beam, ultraviolet light, or visible light. Electron beam radiation, which is also known as ionizing radiation, can be used at an energy level of about 0.1 to about 10 Mrad, preferably at an energy

level of about 1 to about 10 Mrad. Ultraviolet radiation refers to non-particulate radiation having a wavelength within the range of about 200 to about 400 nanometers, preferably within the range of about 250 to 400 nanometers. It is preferred that 300 to 600 Watt/inch (120-240 Watt/cm) ultraviolet lights are used. Visible radiation refers to non-particulate radiation having a wavelength within the range of about 400 to about 800 nanometers, preferably in the range of about 400 to about 550 nanometers. It is preferred that 300 to 600 Watt/inch (120-240 Watt/cm) visible lights are used.

One method to make the abrasive article of the invention is illustrated in Figure 3. Backing 41 leaves an unwind station 42 and at the same time the production tool 46 leaves an unwind station 45. Cavities (not depicted) formed in the upper surface of production tool 46 are coated and filled with an abrasive slurry by means of coating station 44. Alternatively, coating station 44 can be relocated to deposit the slurry on backing 41 instead of the production tool before reaching drum 43 and the same ensuing steps are followed as used for coating the production tooling as described below. Either way, it is possible to heat the abrasive slurry (not shown) and/or subject the slurry to ultrasonics prior to coating to lower the viscosity. The coating station can be any conventional coating means such as drop die coater, knife coater, curtain coater, vacuum die coater or a die coater. During coating the formation of air bubbles should be minimized. The preferred coating technique uses a vacuum die coater, which can be of the type such as described in U.S. Patent Nos. 3,594,865; 4,959,265 and 5,077,870. After the production tool is coated, the backing and the abrasive slurry are brought into contact by any means such that the abrasive slurry

wets the front surface of the backing. In Figure 3, the abrasive slurry is brought into contact with the backing by means of contact nip roll 47, and contact nip roll 47 forces the resulting construction against support drum 43. Next, any convenient form of energy 48 is transmitted into the abrasive slurry that is adequate to at least partially cure the binder precursor. The term partial cure is meant that the binder precursor is polymerized to such a state that the abrasive slurry does not flow from an inverted test tube. The binder precursor can be fully cured once it is removed from the production tool by any energy source. The production tool is rewound on mandrel 49 so that the production tool can be reused again. Additionally, abrasive article 120 is wound on mandrel 121. If the binder precursor is not fully cured, the binder precursor can then be fully cured by either time and/or exposure to an energy source. Additional steps to make the abrasive article according to this first method is further described in U.S. Patent No. 5,152,917 (Pieper et al.) or the above-mentioned U.S. Patent Application No. 08/004,929 (Spurgeon et al.). Other guide rolls are used where convenient and are designated rolls 40.

Relative to this first method, it is preferred that the binder precursor is cured by radiation energy. The radiation energy can be transmitted through the production tool or backing so long as the production tool or backing does not appreciably absorb the radiation energy. Additionally, the radiation energy source should not appreciably degrade the production tool. It is preferred to use a thermoplastic production tool and ultraviolet or visible light.

As mentioned above, in a variation of this first method, the abrasive slurry can be coated onto the backing and not into the cavities of the production

tool. The abrasive slurry coated backing is then brought into contact with the production tool such that the abrasive slurry flows into the cavities of the production tool. The remaining steps to make the abrasive article are the same as detailed above.

A second method for making the abrasive article is illustrated in Figure 4. The production tool 55 is provided in the outer surface of a drum, e.g., as a sleeve which is secured around the circumference of a drum in separate sheet form (e.g., as a heat-shrunk nickel form) in any convenient manner. Backing 51 leaves an unwind station 52 and the abrasive slurry is coated into the cavities of the production tool 55 by means of the coating station 53. The abrasive slurry can be coated onto the backing by any technique such as drop die coater, roll coater, knife coater, curtain coater, vacuum die coater, or a die coater. Again, it is possible to heat the abrasive slurry and/or subject the slurry to ultrasonics prior to coating to lower the viscosity. During coating the formation of air bubbles should be minimized. Then, the backing and the production tool containing the abrasive slurry are brought into contact by a nip roll 56 such that the abrasive slurry wets the front surface of the backing. Next, the binder precursor in the abrasive slurry is at least partially cured by exposure to an energy source 57. After this at least partial cure, the abrasive slurry is converted to an abrasive composite that is bonded or adhered to the backing. The resulting abrasive article 59 is stripped and removed from the production tool at nip rolls 58 and wound onto a rewind station 60. In this method, the energy source can be thermal energy or radiation energy. If the energy source is either ultraviolet light or visible light, the backing should be transparent to ultraviolet or visible light. An example of such a backing is

polyester backing. Other guide and contact rolls can be used where convenient and are designated rolls 50.

In another variation of this second method, the abrasive slurry can be coated directly onto the front surface of the backing by moving coating station 53 to a location upstream from roll 56. The abrasive slurry coated backing is then brought into contact with the production tool such that the abrasive slurry wets into the cavities of the production tool. The remaining steps to make the abrasive article are the same as detailed above.

After the abrasive article is made, it can be flexed and/or humidified prior to converting. The abrasive article can be converted into any desired form such as a cone, endless belt, sheet, disc, etc. before the abrasive article is put into service.

Method of Refining a Workpiece Surface

Another embodiment of this invention pertains to a method of refining a workpiece surface. This method involves bringing into frictional contact the abrasive article of this invention with a workpiece. The term refine means that a portion of the workpiece is abraded away by the abrasive article. Additionally, the surface finish associated with the workpiece surface is reduced after this refining process. One typical surface finish measurement is Ra; Ra is the arithmetic surface finish generally measured in microinches or micrometers. The surface finish can be measured by a profilometer, such as that available under the trade designation Perthometer or Surtronic.

Workpiece

The workpiece can be any type of material such as metal, metal alloy, exotic metal alloy, ceramic, glass, wood, wood like material, composites, painted surface, plastic, reinforced plastic, stone, and combinations thereof. The workpiece may be flat or may have a shape

or contour associated with it. Examples of workpieces include glass ophthalmic lenses, plastic ophthalmic lenses, glass television screens, metal automotive components, plastic components, particle board, cam shafts, crank shafts, furniture, turbine blades, painted automotive components, magnetic media, and the like.

Depending upon the application, the force at the abrading interface can range from about 0.1 kg to over 1000 kg. Generally this range is between 1 kg to 500 kg of force at the abrading interface. Also depending upon the application, there may be a liquid present during abrading. This liquid can be water and/or an organic compound. Examples of typical organic compounds include lubricants, oils, emulsified organic compounds, cutting fluids, soaps, or the like. These liquids may also contain other additives such as defoamers, degreasers, corrosion inhibitors, or the like. The abrasive article may oscillate at the abrading interface during use. In some instances, this oscillation may result in a finer surface on the workpiece being abraded.

An abrasive composite having an adjacent abrasive composite with a different dimension attributes to this relatively fine surface finish. Since a portion of the abrasive composites have different dimensions, the abrasive composites may not perfectly align in a row from the perspective of the apices of pyramidal shapes and the like. For example, Figure 8 includes a representative topographical top view (and side views) of an abrasive article 85 of the invention wherein an abrasive composite therein is designated 80 having a face 82 and apex 81. As seen in Figure 8, the pyramidal shapes, as a whole, align in rows, and therefore, the apices of the abrasive composites are aligned irrespective of the differences in side dimensions

between adjacent abrasive composites facing each other across common grooves. This arrangement results in scratches imparted into the workpiece by the abrasive composites which are continuously crossed over. This continuous crossing of previous scratches results, in the aggregate, in the finer surface finish.

The abrasive article of the invention can be used by hand or used in combination with a machine. At least one or both of the abrasive article and the workpiece is moved relative to the other. The abrasive article can be converted into a belt, tape rolls, disc, sheet, and the like. For belt applications, the two free ends of an abrasive sheet are joined together and a splice is formed. It is also within the scope of this invention to use a spliceless belt. Generally the endless abrasive belt traverses over at least one idler roll and a platen or contact wheel. The hardness of the platen or contact wheel is adjusted to obtain the desired rate of cut and workpiece surface finish. The abrasive belt speed ranges anywhere from about 150 to 5000 meters per minute, generally between 500 to 3000 meters per minute. Again this belt speed depends upon the desired cut rate and surface finish. The belt dimensions can range from about 5 mm to 1 meter wide and from about 5 cm to 10 meters long. Abrasive tapes are continuous lengths of the abrasive article. They can range in width from about 1 mm to 1 meter, generally between 5 mm to 25 cm. The abrasive tapes are usually unwound, traverse over a support pad that forces the tape against the workpiece and then rewound. The abrasive tapes can be continuously feed through the abrading interface and can be indexed. The abrasive disc, which also includes what is known in the abrasive art as "daisies", can range from about 50 mm to 1 meter in diameter. Typically abrasive discs are secured to a back-up pad by an attachment means. These abrasive

discs can rotate between 100 to 20,000 revolutions per minute, typically between 1,000 to 15,000 revolutions per minute.

The features and advantages of the present invention will be further illustrated by the following non-limiting examples. All parts, percentages, ratios, etc, in the examples are by weight unless otherwise indicated.

Experimental Procedure

The following abbreviations are used throughout:

TMPTA: trimethylol propane triacrylate;

TATHEIC: triacrylate of tris(hydroxy ethyl) isocyanurate;

PH2: 2-benzyl-2-N,N-dimethylamino-1-(4-morpholinophenyl)-1-butanone, commercially available from Ciba Geigy Corp. under the trade designation "Irgacure 369";

ASF: amorphous silica filler, commercially available from DeGussa under the trade designation "OX-50";

FAO: fused heat treated aluminum oxide;

WAO: white fused aluminum oxide; and

SCA: silane coupling agent, 3-methacryloxy-propyltrimethoxysilane, commercially available from Union Carbide under the trade designation "A-174".

General Procedure for Making the Abrasive Article

An abrasive slurry was prepared that contained 20.3 parts TMPTA, 8.7 parts TATHEIC, 0.3 parts PH2, 1 part ASF, 1 part SCA and 69 parts of grade P-320 FAO. The slurry was mixed for 20 minutes at 1200 rpm using a high shear mixer.

The production tool was a continuous web made from a polypropylene sheet material commercially available from Exxon under the trade designation "PolyPro 3445". The production tool was embossed off of a nickel-plated

master. The master tool was made by diamond cutting a pattern of varying dimension grooves and indentations according to the computer programs described in the APPENDIX, and then nickel plated. The APPENDIX includes the source code for four computer programs, which, in general, comprises a first program entitled "VARI-1.BAS", which generated and determined random left and right angles for side surfaces of five sided pyramidal shapes and also the material included angles for these shapes; the second program entitled "VARI-STAT.BAS" statistically tallied the number and values of the left, right, and material included angles in x and y coordinates in the array of shapes to assure randomness; the third program entitled "TOPVIEW.BAS" took the random angle file and calculated where the valleys and peaks appear for the shapes having the angles determined by the first program for a square inch (6.5 cm^2) and printed out a display on a computer screen or printer of the topography of the array of shapes; and the fourth program "MAKETAPE.BAS" took the determined angles and generated a code to control the number and type of grooves required to be cut by the diamond turning machine to make a 22.5 inch (57 cm) wide pattern of random shapes generated by the first program.

In general, the production tool, as made from the master tool made using the above-mentioned four programs, contained an array of cavities that were inverted five sided pyramids (inclusive of the mouth of the cavity as a "base") that had a constant depth of about 355 micrometers but varied in dimension between 8 and 45 degrees for adjacent cavities in terms of the angle made by side faces with the intersection of a plane extending normal to the plane of tool and the material included angle or apex angle of each composite was at least 25 degrees.

The abrasive article was made by a method and arrangement generally depicted in Figure 3. This process was a continuous process that operated at about 15.25 meters/minute. The backing was a J weight rayon backing that contained a dried latex/phenolic presize coating to seal the backing. The abrasive slurry was knife-coated onto a production tool with a 76 micrometer knife gap (3 mil) and about a 15 cm wide coating area onto the production tool. The nip pressure, such as exerted by roll 47 in Figure 3, between the production tool and the backing was about 40 pounds. The energy source was one visible-light lamp, which contained a V-bulb made by Fusion Systems, Co., which operated at 600 Watts/inch (240 Watt/cm). After curing the abrasive slurry, the resulting coated abrasive was thermally cured for 12 hours at 240°F (116°C) to final cure the phenolic presize of the backing.

Test Procedure I

The coated abrasive article was converted into 7.6 cm by 335 cm endless belt and tested on a constant load surface grinder. A pre-weighed, 4150 mild steel workpiece approximately 2.5 cm by 5 cm by 18 cm was mounted in a holder. The workpiece was positioned vertically, with the 2.5 cm by 18 cm face facing an approximately 36 cm diameter 65 Shore A durometer serrated rubber contact wheel with one on one lands over which was entrained the coated abrasive belt. The workpiece was then reciprocated vertically through an 18 cm path at the rate of 20 cycles per minute, while a spring loaded plunger urged the workpiece against the belt with a load of 4.5 kg (10 lbs) as the belt was driven at about 2050 meters per minute. After thirty seconds elapsed grinding time, the workpiece holder assembly was removed and re-weighed, the amount of stock removed calculated by subtracting the abraded

weight from the original weight, and a new, pre-weighed workpiece and holder were mounted on the equipment. Additionally, the surface finish (Ra) and, in some cases, the Rtm, of the workpiece was also measured and these procedures will be described below. The test endpoint was when the amount of steel removed in the thirty second interval was less than one third the value of the steel removed in the first thirty seconds of grinding or until the workpiece burned, i.e., became discolored.

Test Procedure II

The same procedure as Test Procedure I was used except that a 1018 mild steel workpiece was used.

Test Procedure III

A maple dowel rod that had a diameter of approximately 3 cm was installed on a lathe. The dowel rod was rotated at about 3800 rpm. A strip of abrasive article (1 inch (2.54 cm) wide and 12 inches (30.5 cm) long) was held against the dowel rod without any oscillation for approximately 15 to 20 seconds. After abrading, the dowel rod was stained with a cherry oil stain commercially available from Watco.

Ra is a common measure of roughness used in the abrasives industry. Ra is defined as the arithmetic mean of the departures of the roughness profile from the mean line. Ra was measured with a profilometer probe, which was a diamond tipped stylus. In general, the lower the Ra value was, the smoother or finer the workpiece surface finish. The results were recorded in micrometers. The profilometer used was a Perthen M4P.

Rtm is a common measure of roughness used in the abrasive industry. Rtm is defined as the mean of five individual roughness depths of five successive measuring lengths, where an individual roughness depth is the vertical distance between the highest and lowest points in a measuring length. Rtm is measured the same

as Ra. The results are recorded in micrometers. In general, the lower the Rtm, the smoother the finish.

Examples

Examples 1, 1A and Comparative Examples A, AA

Abrasive articles representative of the invention were compared with conventional coated abrasive articles having uniformly shaped and dimensioned abrasive composites. Example 1 was made according to the "General Procedure for Making the Abrasive Article" describe herein. Comparative Example A was a grade P320 3M 201E Three-M-ite Resin Bond cloth JE-VF coated abrasive commercially available from 3M Company, St. Paul, MN. These abrasive products were tested according to Test Procedure I and the test results can be found in Table 1. Also, additional Example 1A and Comparative Example AA were performed wherein Example 1 and Comparative Example A were repeated, except that Test Procedure II was used in lieu of Test Procedure I. The results also are summarized in Table 1.

Table 1

Run	Ex. 1	C.Ex. A	Ex. 1A	C. Ex. AA
Init. Cut (grams)	12.2	15.3	13.3	11.8
Init. Ra (μm) Init.Rtm (μm)	0.86	0.88	0.98 9.43	1.18 10.66
Total Cut (grams)	283.6	156.8	255.5	247.2
Final Ra(μm) Final Rtm (μm)	0.33	0.43	0.37 3.11	0.40 3.92

The above results show that the abrasive articles of the present invention, as represented by Examples 1 and 1A, demonstrated higher cut and provided finer finish than the comparison examples using exclusively identically shaped abrasive composites.

Example 2 and Comparative Examples B through E

This set of examples compared the abrasive article of the invention with abrasive articles that had only one commonly shaped and dimensioned type of abrasive composite present on the backing. All of these examples were made according to "General Procedure for Making the Abrasive Article," described above, except for the following changes. The abrasive slurry consisted of 20.3 parts TMPTA, 8.7 parts TATHEIC, 1 part PH2, 1 part ASF, 1 part SCA, and 69 parts of 40 micrometer WAO. Also, the production tool for Comparative Examples B through E was an embossed polypropylene thermoplastic continuous web that contained five sided pyramidal type cavities (inclusive of the mouth of the cavity as a "base"). The cavities for Comparative Examples B through E were all identical in dimensions and the cavities butted up against one another. The height of the cavities for Comparative Example B was about 178 micrometers, for Comparative Example C was about 63.5 micrometers, for Comparative Example D was about 711 micrometers and Comparative Example E was about 356 micrometers.

Example 2 and Comparative Examples B through E then were tested according to Test Procedure III above. The stained maple dowel rod abraded with Comparative Examples B through E showed evidence of grooves visible by the naked eye. In contrast, the stained maple dowel rod abraded with Example 2 representing the present invention showed no evidence of grooves visible by the

naked eye and produced a very fine finish on the wood workpiece.

Various modifications and alterations of this invention will become apparent to those skilled in the art without departing from the scope and spirit of this invention, and it should be understood that this invention is not to be unduly limited to the illustrative embodiments set forth herein.

Appendix

```
'*****************************
'**Program : VARI-1.BAS      *
******************************
' VARI-1.BAS - Creates random left and right half
angles
'
DECLARE SUB showangles ()
DIM SHARED LEFTANG(3000) AS INTEGER
DIM SHARED RIGHTANG(3000) AS INTEGER
'******* Begin Main Program *****
PI = 3.141592654#
RANDOMIZE TIMER
CLS
INPUT "WHAT IS THE TOOL ANGLE  ", ToolAng
INPUT "WHAT IS THE MINIMUM HALF ANGLE  ", MinHalfAng
INPUT "WHAT IS THE MAXIMUM HALF ANGLE  ", MaxHalfAng
INPUT "WHAT IS THE MINIMUM INCLUDED ANGLE OF THE
MATERIAL  ", MinInclAng
ANG1 = 45
'ANG1 is the previous grooves Right half angle
'ANG1 & 2 are used to check the MinInclAng
FOR I =  1 TO 2500 STEP 2
     '** Calculate Odd Numbered Groove Angles ****
     FOR T = 1 TO INT(RND * 100 + 1): NEXT T
'This is a random delay
     IF MinInclAng - ANG1 > MinHalfAng THEN
       min = MinInclAng - ANG1
     ELSE
       min = MinHalfAng
     END IF
     LEFTANG(I) = INT(RND * (MaxHalfAng - min + 1)+
min)
     IF ToolAng - LEFTANG(I) > MinHalfAng THEN
        min = ToolAng - LEFTANG(I)
     ELSE
```

```
            min = MinHalfAng
         END IF
         RIGHTANG(I) = INT(RND * (MaxHalfAng - (min) + 1) +
    (min))
         ANG2 = RIGHTANG(I)
         '** End Calculate Odd Number Groove angles **
         '** Begin Calculating Even Numbered Groove angles
         **
    FOR T = 1 TO INT(RND * 100 + 1): NEXT T
    'This is a random delay
    RIGHTANG(I + 1) = INT(RND * (MaxHalfAng - MinHalfAng +
    1) + MinHalfAng)
    IF ToolAng - RIGHTANG(I + 1) > MinHalfAng THEN
       min = ToolAng - RIGHTANG(I + 1)
    ELSE
       min = MinHalfAng
    END IF
    IF MinInclAng - ANG2 > min THEN
       min = MinInclAng - ANG2
    ELSE
       min = min
    END IF
    LEFTANG(I + 1) = INT(RND * (MaxHalfAng - (min) 1) +
    (min))
    ANG1 = RIGHTANG(I + 1)
    '** End Calculating Even Numbered Groove Angles **

    NEXT I
    CALL showangles
    OPEN "RANANG.TXT" FOR OUTPUT AS #3
    PRINT #3, "RANDOM ANGLE GENERATOR"
    PRINT #3, "LEFT ANG   RIGHT ANG"
    FOR I = 1 TO 2500
      PRINT #3, LEFTANG(I); RIGHTANG(I)
    NEXT I
```

```
CLOSE 3

'****************** End Main Program*************
'
SUB showangles 'This subroutine shows the first 30
grooves

CLS
SCREEN 9
COLOR 3
SLEEP 2
PI    3.141592654#
     FOR I = 1 TO 30
       'LOCATE 1, 1: PRINT LEFTANG(I), RIGHTANG(I),
LEFTANG(I) + RIGHTANG(I)
       A = (TAN(LEFTANG(I) * PI / 180) * 200)
       LINE (200, 100)-(200 - A, 300), 3
       B = (TAN(RIGHTANG(I) * PI / 180) * 200)
       LINE (200, 100)-(200 + B, 300), 3
       FOR T = 1 TO 200000: NEXT T
       LINE (200, 100)-(200 - A, 300), 0
       LINE (200, 100)-(200 + B, 300), 0
     NEXT I
END SUB


'*****************************
'** Program : VARISTAT.BAS    *
*****************************

DECLARE SUB SETGRAPH2 () 'Graph for Included Angles
DECLARE SUB ANGLEGEN ()       'Main Subroutine
DECLARE  SUB XGEN ()          'Subroutine for Tests
only
DECLARE  SUB SETGRAPH () 'Graph for Half Angles
```

```
DIM SHARED ANGLEFT(2501) AS INTEGER     'Array for left
half angles Direction 1
DIM SHARED ANGRIGHT(2501) AS INTEGER    'Array for
right half angles Direction 1
DIM SHARED ANGLEFT2(2501) AS INTEGER    'Array for left
half angles Direction 2
DIM SHARED ANGRIGHT2(2501) AS INTEGER   'Array for
right half angles Direction 2
DIM SHARED HALF(8 TO 45) AS INTEGER     'Array to tally
number of angles between 8 and 45 Direction 1
DIM SHARED HALF2(8 TO 45) AS INTEGER    'Array to tally
number of angles between 8 and 45 Direction 2
DIM SHARED ACCUM(O TO 100) AS INTEGER   'Array to tally
number of included angles between 40 and 90 Dir
DIM SHARED ACCUM2(0 TO 100) AS INTEGER  'Array to tally
number of included angles between 40 and 90 Dir

CLS
CALL ANGLEGEN
'CALL  XGEN  'This was for test purposes only
SUB  ANGLEGEN
CALL SETGRAPH
OPEN "RANANG.TXT" FOR INPUT AS #3
'Two different .TXT files would have been created,
however here we use the same file
OPEN "RANANG.TXT" FOR INPUT AS #4
INPUT #3,  A$
INPUT #3,  B$
INPUT #4,  A$
INPUT #4,  B$
FOR I = 1 TO 2500
     INPUT #3, ANGLEFT(I)
     INPUT #3, ANGRIGHT(I)
     INPUT #4, ANGLEFT2(I)
     INPUT #4, ANGRIGHT2(I)
NEXT  I
```

```
CLOSE 3, 4

FOR I = 1 TO 2500
    HALF(ANGLEFT(I)) = HALF(ANGLEFT(I)) + 1
    HALF2(ANGRIGHT(I)) = HALF2(ANGRIGHT(I)) + 1
NEXT I

LOCATE 2, 10: COLOR 11
PRINT  "First Direction Total Left Half Angle"
LOCATE 3, 10: COLOR  12
PRINT  "First Direction Total Right Half Angle"

FOR I = 8 TO 45
   LINE (I, 0)-(I, HALF(I)), 11
   LINE (I + .5, 0)-(I + .5, HALF2(I)), 12
   HALF(I) = 0
   HALF2(I) = 0
NEXT I
SLEEP

CALL SETGRAPH
LOCATE 2, 10: COLOR 11
PRINT "Second Direction Total Left Half Angle"
LOCATE 3, 10: COLOR 12
PRINT "Second Direction Total Right Half Angle"

FOR I = 1 TO 2500
    HALF(ANGLEFT2(I)) = HALF(ANGLEFT2(I)) + 1
    HALF2(ANGRIGHT2(I)) = HALF2(ANGRIGHT2(I)) + 1
NEXT I

FOR I = 8 TO 45
   LINE (I, 0)-(I, HALF(I)), 11
   HALF(I) = 0
   LINE (I + .5, 0)-(I + .5, HALF2(I)), 12
   HALF2(I) = 0
```

```
NEXT I
SLEEP

CALL SETGRAPH2
LOCATE 2, 10: COLOR 11
PRINT "First Direction Total Included Angles (Left +
Right Half Angle)"
LOCATE 3, 10: COLOR 12
PRINT "Second Direction Total Included Angles (Left +
Right Half Angle)"

FOR I = 1 TO 2500
   ACCUM(ANGLEFT(I) + ANGRIGHT(I)) = ACCUM(ANGLEFT(I) +
ANGRIGHT(I)) + 1
   ACCUM2(ANGLEFT2(I) + ANGRIGHT2(I)) =
ACCUM2(ANGLEFT2(I) + ANGRIGHT2(I)) + 1
NEXT I
FOR I = 40 TO 90
    LINE (I, 0)-(I, ACCUM(I)), 11
    ACCUM(I) = 0
    LINE (I + .5, 0)-(I + .5, ACCUM2(I)), 12
    ACCUM2(I) = 0
NEXT I
SLEEP
END SUB

SUB SETGRAPH

SCREEN 9
WINDOW (4, -30)-(50, 200)
CLS

LINE (6, 0)-(6, 200), 3
LINE (6, 0)-(50, 0), 3
LINE (6, 195)-(50, 195), 3
LINE (6, 105)-(50, 105), 3
```

```
LINE (6, 50)-(50, 50), 3
LINE (6, 150)-(50, 150), 3
LOCATE 23, 7: PRINT "8"
LOCATE 23, 72: PRINT "45"
LOCATE 23, 40: PRINT "27"
LOCATE 22, 3: PRINT "1"
LOCATE 1, 1: PRINT "200"
LOCATE 11, 1: PRINT "100",
END SUB

SUB SETGRAPH2
SCREEN 9
WINDOW (37, -30)-(95, 200)
CLS

LINE (39, 0)-(39, 200), 3
LINE (39, 0)-(95, 0), 3
LINE (39, 198)-(95, 198), 3
LINE (39, 102)-(95, 102), 3
LINE (39, 50)-(95, 50), 3
LINE (39, 150)-(95, 150), 3
LOCATE 23, 4: PRINT "40"
LOCATE 23, 73: PRINT "90"
LOCATE 23, 39: PRINT  "65"
LOCATE 22, 3: PRINT "1"
LOCATE 1, 1: PRINT "200"
LOCATE 11, 1: PRINT "100"
END SUB

SUB XGEN    'This subroutine was for test purposes only

CALL SETGRAPH
OPEN "RANANG.TXT" FOR INPUT AS #3
INPUT #3, A$
INPUT #3, B$
FOR I = 1 TO 2500
```

```
  INPUT #3, ANGLEFT(I)
  INPUT #3, ANGRIGHT(I)
NEXT I
FOR I = 1 TO 2500
    HALF(ANGLEFT(I)) = HALF(ANGLEFT(I)) + 1
NEXT I

FOR I = 8 TO 45
   LINE (I, 0)-(I, HALF(I)), 11
   HALF(I) = 0
NEXT I
SLEEP

CALL SETGRAPH
FOR I = 1 TO 2500
    HALF(ANGRIGHT(I)) = HALF(ANGRIGHT(I)) + 1
NEXT I
FOR I = 8 TO 45
   LINE (I, 0)-(I, HALF(I)), 11
   HALF(I) = 0
NEXT I
SLEEP
CALL SETGRAPH2
FOR I = 1 TO 2500
   ACCUM(ANGLEFT(I) + ANGRIGHT(I)) = ACCUM(ANGLEFT(I) +
ANGRIGHT(I)) + 1
NEXT I
FOR I = 40 TO 90
    LINE (I, 0)-(I, ACCUM(I)), 11
    ACCUM(I) = 0
NEXT I
SLEEP
END SUB
```

```
*******************************
'** Program : TOPVIEW.BAS    *
*******************************
'* In general it takes the random angle data file,
calculates where the valleys and peaks are, draws black
straight lines for the valleys, then connects the peaks
across the diagonal.  Then it displays the output on
the screen or an HP 7475 plotter.  *
********************************
DECLARE SUB PLOTPEAKS ()
DECLARE SUB PLOTDOTS ()
DECLARE SUB LINES ()
DECLARE SUB DIAGONAL ()
DIM SHARED ML(2500) AS INTEGER
DIM SHARED MR(2500) AS INTEGER
DIM SHARED NL(2500) AS INTEGER
DIM SHARED NR(2500) AS INTEGER

DIM SHARED M(5000) AS DOUBLE
DIM SHARED N(5000) AS DOUBLE
COMMON SHARED PI, X, GROOVES
PI = 3.141592654#

GROOVES = 1000
OPEN "RANANG.TXT" FOR INPUT AS #2
OPEN "RANANG.TXT" FOR INPUT AS #3
INPUT "ENTER IN THE SQUARE SIZE YOU WOULD LIKE (.2 ->
1.5 INCHES)  ", X

INPUT #2, A$
INPUT #2, B$
FOR I = 1 TO GROOVES
  INPUT #2, ML(I)
  INPUT #2, MR(I)
NEXT I
CLOSE 2
```

```
INPUT #3, A$
INPUT #3, B$
FOR I = 1 TO GROOVES
   INPUT #3, NL(I)
   INPUT #3, NR(I)
NEXT I
CLOSE 3

FOR I = 1 TO GROOVES
  M(I * 2 - 1) = M((I - 1) * 2) + TAN(ML(I) * PI / 180)
* .014
  M(I * 2) = M(I * 2 - 1) + TAN(MR(I) * PI / 180) *
.014
  N(I * 2 - 1) = N((I - 1) * 2) + TAN(NL(I) * PI / 180)
* .014
  N(I * 2) = N(I * 2 - 1) + TAN(NR(I) * PI / 180) *
.014
NEXT I

LOCATE 15, 15
INPUT "Would you like to see the data on the (S)creen
or (P)lotter", ans$
ans$ = UCASE$(ans$)

IF ans$ = "S"  THEN
   SCREEN 9
   COLOR 0
   WINDOW SCREEN (-(X / 10), -(X / 10))-(X, (X + X /
10) * (.75 - .75 * .138))
   PAINT (X / 2, X / 2), 15
   CALL LINES
   SLEEP
   CLS
   PAINT (X / 2, X / 2), 15

   CALL DIAGONAL
```

```
END IF
IF ans$ = "P" THEN
   CALL PLOTDOTS
   CALL PLOTPEAKS

   SLEEP
END IF

SUB DIAGONAL
FOR I = 1 TO GROOVES * 2 STEP 2
  'LINE (M(I), N(1))-(M(I), 10)
  'LINE (M(1), N(I))-(10, N(I))
NEXT I

FOR I = 1 TO GROOVES * 2 - 2 STEP 2
  LINE (M(I), -.014)-(M(I + 1), 0)
  LINE (M(I + 1), 0)-(M(I + 2), -.014)
NEXT I

LINE (M(1), -.014)-(M(1), -.02)
LINE -(M(GROOVES * 2 - 2), -.02)
LINE -(M(GROOVES * 2 - 2), -.014)
FOR I = 1 TO GROOVES * 2 - 2 STEP 2
  LINE (-.014, N(I))-(0, N(I + 1))
  LINE (0, N(I + 1))-(-.014, N(I + 2))
NEXT I
LINE (-.014, N(1))-(-.02, N(1))
LINE -(-.02, N(GROOVES * 2 - 2))
LINE -(-.014, N(GROOVES * 2 - 2))

FOR NN = 2 TO GROOVES * 2 - 2 STEP 2
  FOR MM = 2 TO GROOVES * 2 - 2 STEP 2
      'LINE (M(MM), N(NN))-(M(MM + 1), N(NN + 1)), 2
      'LINE (M(MM), N(NN))-(M(MM + 1), N(NN - 1)), 4
      'LINE (M(MM), N(NN))-(M(MM - 1), N(NN + 1)), 4
      'LINE (M(MM), N(NN))-(M(MM - 1), N(NN - 1)), 2
```

```
      LINE (M(MM), N(NN))-(M(MM + 2), N(NN + 2)), 2
      'LINE (M(MM), N(NN))-(M(MM + 2), N(NN - 2)), 4
      PSET (M(MM), N(NN)), 4
      IF M(MM - 1) > X THEN GOTO STOPMM
      IF N(NN - 1) > (X + X / 10) * (.75 - .75 * .138)
THEN GOTO STOPNN
  NEXT MM
STOPMM:
NEXT NN
'PAINT (M(5) + (M(6) - M(5)) / 2, N(6) - (N(6) - N(5))
/ 2), 11
'CIRCLE (M(5) + (M(6) - M(5)) / 2, N(6) - (N(6) - N(5))
/ 2), .001, 11
STOPNN:
BEEP
END SUB

SUB LINES
FOR I = 1 TO 200 STEP 2
  LINE (M(I), N(1))-(M(I), 10)
  LINE (M(1), N(I))-(10, N(I))
NEXT I

FOR I = 1 TO 198 STEP 2
  LINE (M(I), -.014)-(M(I + 1), 0)
  LINE (M(I + 1), 0)-(M(I + 2), -.014)
NEXT I
LINE (M(1), -.014)-(M(1), -.02)
LINE -(M(198), -.02)
LINE -(M(198), -.014)
FOR I = 1 TO 198 STEP 2
  LINE (-.014, N(I))-(O, N(I + 1))
  LINE (0, N(I + 1))-(-.014, N(I + 2))
NEXT I
LINE (-.014, N(1))-(-.02, N(1))
LINE -(-.02, N(198))
```

```
LINE -(-.014, N(198))

FOR NN = 2 TO 198 STEP 2
  FOR MM = 2 TO 198 STEP 2
      LINE (M(MM), N(NN))-(M(MM + 1), N(NN + 1)), 2
      LINE (M(MM), N(NN))-(M(MM + 1), N(NN - 1)), 4
      LINE (M(MM), N(NN))-(M(MM - 1), N(NN + 1)), 4
      LINE (M(MM), N(NN))-(M(MM - 1), N(NN - 1)), 2
      IF M(MM - 1) > X THEN GOTO 300
      IF N(NN - 1) > (X + X / 10) * (.75 - .75 * .138)
THEN GOTO 200
  NEXT MM
300
NEXT NN
'PAINT (M(5) + (M(6) - M(5)) / 2, N(6) - (N(6) - N(5))
/ 2), 11
'CIRCLE (M(5) + (M(6) - M(5)) / 2, N(6) - (N(6) - N(5))
/ 2), .001, 11
200
BEEP
END SUB

SUB PLOTDOTS
'WINDOW SCREEN (-(X / 10), -(X / 10))-(X, (X + X / 10)
* (.75 - .75 * .138))

OPEN "COM1:9600,S,7,1,RS,CS65535,DS,CD" FOR RANDOM AS
#4
'PRINT #4, USING "IP;
SC##.#####,##.#####,##.#####,##.#####;"; (-(X / 10));
(X); (-(X / 10)); ((X + X / 10
'PRINT #4, USING "IP250,596,7470,7796;
SC##.#####,##.#####,##.#####,##.#####;"; 0; 4; 0; 3
PRINT #4, "IN;IP250,596,7443,7796; SC0,1,0,1;"
PRINT #4, "VS30;"
PRINT #4, "SP1;"
```

```
FOR I = 1 TO GROOVES * 2 STEP 2
  'LINE (M(I), N(1))-(M(I), 10)
  'LINE (M(1), N(I))-(10, N(I))
NEXT I

PRINT #4, USING "PA ##.#####, -.014;"; M(1)
PRINT #4, "PD;"

FOR I = 2 TO GROOVES * 2 - 2 STEP 2
  'LINE (M(I), -.014)-(M(I + 1), 0)
  PRINT #4, USING "PA ##.#####, 0"; M(I)
  'LINE (M(I + 1), 0)-(M(I + 2), -.014)
  PRINT #4, USING "PA ##.#####,-.014"; M(I + 1)
  P = I + 1
  IF M(I + 1) > X THEN GOTO 600
NEXT I
600
'LINE (M(1), -.014)-(M(1), -.02)
PRINT #4, USING "PA ##.#####, -.03;"; M(P)
'LINE -(M(P), -.02)
PRINT #4, USING "PA ##.#####, -.03;"; M(1)
'LINE -(M(P), -.014)
PRINT #4, USING "PA ##.#####,-.014;PU;"; M(1)
PRINT #4, USING "PA -.014,##.#####;PD;"; N(1)
FOR I = 2 TO GROOVES * 2 - 2 STEP 2
  'LINE (-.014, N(I))-(0, N(I + 1))
  PRINT #4, USING "PA 0,##.#####;"; N(I)
  'LINE (0, N(I + 1))-(-.014, N(I + 2))
  PRINT #4, USING "PA -.014,##.#####;"; N(I + 1)
  Q = I+ 1
  IF N(I + 1) > X THEN GOTO 700
NEXT I
700
'LINE (-.014, N(1))-(-.02, N(1))
PRINT #4, USING "PA -.03,##.#####;"; N(Q)
'LINE -(-.02, N(Q))
```

```
PRINT #4, USING "PA -.03,##.#####;"; N(1)
'LINE -(-.014, N(Q))
PRINT #4, USING "PA -.014,##.#####;PU;"; N(1)
PRINT #4, "SP4;"

PRINT #4, USING "PA ##.#####,##.#####;PD;"; M(2); N(2)
A = 2
FOR B = 2 TO P STEP 2
  FOR COUNT = 0 TO Q - 1 STEP 2
      'LINE (M(MM), N(NN))-(M(MM + 2), N(NN + 2)), 2
      PRINT #4, USING "PD;PA ##.#####,##.#####;"; M(B +
COUNT) N (A + COUNT)
      IF M(B + COUNT - 1) > X THEN GOTO 400
      IF N(A + COUNT - 1) > X THEN GOTO 400
  NEXT COUNT
400
PRINT #4, "PU;"
PRINT #4, USING "PA ##.#####,##.#####;"; M (B + 2); N
(A)
NEXT B

PRINT #4, USING "PA ##.#####,##.#####;PD;"; M(2); N(4)
B = 2
FOR A = 4 TO Q STEP 2
  FOR COUNT = 0 TO P - 1 STEP 2
      'LINE (M(MM), N(NN))-(M(MM + 2), N(NN + 2)), 2
      PRINT #4, USING "PD;PA ##.#####,##.#####;"; M(B +
COUNT); N(A + COUNT)
      IF M(B + COUNT - 1) > X THEN GOTO 401
      IF N(A + COUNT - 1) > X THEN GOTO 401
  NEXT COUNT
401
PRINT #4, "PU;"
PRINT #4, USING "PA ##.#####,##.#####;"; M(B); N(A + 2)
NEXT A
```

```
'PRINT #4,
"PA.25,.25;PD;PA.75,.25;PA.75,.75;PA.25,.75;PA.25,.25;"
500
BEEP
CLOSE 4
END SUB
SUB PLOTPEAKS

OPEN "COM1:9600,S,7,1,RS,CS65535,DS,CD" FOR RANDOM AS
#4
PRINT #4, "IN;IP250,596,7443,7796; SCO,1,0,1;"

PRINT #4, "VS50;"

PRINT #4, "SP1;"

PRINT #4, USING "PA ##.#####, -.014;"; M(1)
PRINT #4, "PD;"

FOR I = 2 TO GROOVES * 2 - 2 STEP 2
  PRINT #4, USING "PA ##.#####, 0"; M(I)
  PRINT #4, USING "PA ##.#####,-.014"; M(I + 1)
  P = I + 1
  IF M(I + 1) > X THEN GOTO 1600
NEXT I
1600

PRINT #4, USING "PA ##.#####, -.03;"; M(P)
PRINT #4, USING "PA ##.#####, -.03;"; M(1)
PRINT #4, USING "PA ##.#####,-.014;PU;"; M(1)

PRINT #4, USING "PA -.014,##.#####;PD;"; N(1)
FOR I = 2 TO GROOVES * 2 - 2 STEP 2
  PRINT #4, USING "PA 0,##.#####;"; N(I)
  PRINT #4, USING "PA -.014,##.#####;"; N(I + 1)
  Q = I + 1
```

```
  IF N(I + 1) > X THEN GOTO 1700
NEXT I
1700

PRINT #4, USING "PA -.03,##.#####;"; N(Q)
PRINT #4, USING "PA -.03,##.#####;"; N(1)
PRINT #4, USING "PA -.014,##.#####;PU;"; N(1)

FOR I = 1 TO P STEP 4
  PRINT #4, USING "PA
##.#####,##.#####;PD;PA##.#####,##.#####;PU;"; M(I);
N(1); M(I); N(Q)
  PRINT #4, USING "PA
##.#####,##.#####;PD;PA##.#####,##.#####;PU;"; M(I +
2); N(Q); M(I + 2); N(1)
NEXT I

FOR I = 1 TO Q STEP 4
  PRINT #4, USING "PA
##.#####,##.#####;PD;PA##.#####,##.#####;PU;"; M(1);
N(I); M(P); N(I)
  PRINT #4, USING "PA
##.#####,##.#####;PD;PA##.#####,##.#####;PU;"; M(P);
N(I + 2); M(1); N(I + 2)
NEXT I

PRINT #4, "SP4;VS20;"

PRINT #4, USING "PA ##.#####,##.#####;"; M(1); N(1)
A = 1
FOR B = 1 TO P STEP 2
  FOR COUNT = 0 TO Q - 1 STEP 1
      PRINT #4, USING "PD;PA ##.#####,##.#####;"; M(B +
COUNT); N(A + COUNT)
      IF M(B + COUNT - 1) > X THEN GOTO 1400
      IF N(A + COUNT - 1) > X THEN GOTO 1400
```

```
  NEXT COUNT
1400
PRINT #4, "PU;"
PRINT #4, USING "PA ##.#####,##.#####;"; M(B + 2); N(A)
NEXT B

PRINT #4, "SP3;"
PRINT #4, USING "PA ##.#####,##.#####;"; M(P); N(1)
A = 1
FOR B = P TO 1 STEP -2
  FOR COUNT = 0 TO Q - 1 STEP 1
      PRINT #4, USING "PD;PA ##.#####,##.#####;"; M(B -
COUNT); N(A + COUNT)
      IF B - COUNT 1 = 0 THEN GOTO 2500
      IF A + COUNT = Q THEN GOTO 2500
  NEXT COUNT
2500
PRINT #4, "PU;"
IF B - 2 <= 0 THEN GOTO 2000
PRINT #4, USING "PA ##.#####,##.#####;"; M(B - 2); N(A)
NEXT B
2000

PRINT #4, "SP4;"
PRINT #4, USING "PA ##.#####,##.#####;"; M(1); N(3)
B = 1
FOR A = 3 TO Q STEP 2
  FOR COUNT = 0 TO P - 1 STEP 1
      PRINT #4, USING "PD;PA ##.#####,##.#####;"; M(B +
COUNT); N(A + COUNT)
      IF M(B + COUNT - 1) > X THEN GOTO 1401
      IF N(A + COUNT - 1) > X THEN GOTO 1401
  NEXT COUNT
1401
PRINT #4, "PU;"
PRINT #4, USING "PA ##.#####,##.#####;"; M(B); N(A + 2)
```

```
NEXT A

PRINT #4, "SP3;"
PRINT #4, USING "PA ##.#####,##.#####;"; M(P); N(3)
B = P
FOR A = 3 TO Q STEP 2
  FOR COUNT = 0 TO Q - 1 STEP 1
      PRINT #4, USING "PD;PA ##.#####,##.#####;"; M(B -
COUNT); N(A + COUNT)
      IF B - COUNT - 1 = 0 THEN GOTO 2400
      IF A + COUNT = Q THEN GOTO 2400
  NEXT COUNT
2400
PRINT #4, "PU;"
PRINT #4, USING "PA ##.#####,##.#####;"; M(B); N(A + 2)
NEXT A

BEEP
CLOSE 4
END SUB
```

```
'******************************
'** Program : MAKETAPE.BAS    *
'******************************

'MAKETAPE.BAS
'        1)  Ask for the real tool angle
'        2)  Read in all Left and Right angles
'        3)  Figure out how many grooves it will take to
             make a 22.5 inch wide pattern
'        4)  Write the Code
'
'
'
```

```
DECLARE SUB STOPFANUK ()   ' Code to shut down DTM
DECLARE SUB STARTFANUK () ' Code to start up DTM
DECLARE SUB XthenLEFT (A!) ' Code generation for: X move then Left angle plunge
DECLARE SUB ROTATEthenRIGHT (A!) ' Code generation for: Rotate C then Right angle plunge
DECLARE SUB XthenRIGHT (A!)  ' Code generation for: X move then Right angle plunge
DECLARE SUB ROTATEthenLEFT (A!) ' Code generation for: Rotate C then Left angle plunge

'* LEFT() - array to store the left angle information
'* RIGHT() - array to store the right angle information
'* XMOVE() - array to store the X distance between grooves

DIM SHARED LEFT(2500) AS INTEGER, RIGHT(2500) AS INTEGER
DIM SHARED XMOVE(2500) AS DOUBLE
COMMON SHARED TOOLANG AS DOUBLE, CABS AS DOUBLE, XPOS AS DOUBLE

'******** BEGIN MAIN PROGRAM *********
PI = 3.141592654#

CLS
LOCATE 5, 5
INPUT "WHAT IS THE REAL TOOL ANGLE  ", TOOLANG
INPUT "WHAT IS THE PEAK HEIGHT  ", Height

OPEN "RANANG.TXT" FOR INPUT AS #3     'Opens data file of angles
INPUT #3, A$
INPUT #3, B$
```

```
FOR I = 1 TO 2500  'Reads all Left and Right angles
from data file
  INPUT #3, LEFT(I)
  INPUT #3, RIGHT(I)
NEXT I
CLOSE 3


XMOVE(1) = TAN(LEFT(1) * PI / 180) * Height  ' This
formula calculates the  horizontal movement for the
first groove

XPOS = XPOS + XMOVE(1)
FOR I = 2 TO 2500
  XMOVE(I) = TAN(RIGHT(I - 1) * PI / 180) *
Height + TAN(LEFT(I) * PI / 180) * Height

' This formula calculates the horizontal movement
  XPOS = XPOS + XMOVE(I)
  P = I
' P is the number of grooves
  IF XPOS > 22.5 THEN GOTO 100
' Checks to make sure our pattern width is < 22.5
NEXT I
100

LOCATE 10, 10: PRINT USING "GROOVES = ####
: PATTERN WIDTH = ##.####"; P; XPOS
XPOS = 0
OPEN "FANUK.TXT" FOR OUTPUT AS #3
PRINT "WRITING TO FILE"

CALL STARTFANUK   '* This Block of code Generates the
CNC file to run the FANUK controller
FOR I = 1 TO P STEP 2                          '*
  CALL XthenLEFT(I)                            '*
```

```
  CALL ROTATEthenRIGHT(I)                         '*
  CALL XthenRIGHT(I + 1)                          '*
  CALL ROTATEthenLEFT(I + 1)                      '*
NEXT I                                            '*
CALL STOPFANUK                                    '*
PRINT "DONE"

CLOSE  3
'********** END MAIN PROGRAM ***************

'*****The information below describes the two
subroutines of the CNC code ******

'THE SUBROUTINES 0171 & 0172 ARE AS FOLLOWS

'0171;
'G91 G01 Y 0.00200 F 1.0;
'G91 G01 Y 0.01587 F 0.03;
'G91 G01 Y 0.00013 F 0.005;
'G04P245;
'G91 G01  -0.013 F 1.0;
'M99;
';

'0172;
'G91 G01 Y 0.01287 F 0.03;
'G91 G01 Y 0.00013 F 0.005;
'G04P245;
'G91 G01 Y -0.018 F 1.0;
'M99;
';

SUB ROTATEthenLEFT (A)

CABS = -1 * (LEFT(A) + 90) + TOOLANG
PRINT #3, USING "G01 G90 C ##.###### F 300.0;"; CABS
```

```
PRINT #3, "M98 P172 L1;"

END SUB

SUB ROTATEthenRIGHT,(A)

CABS = -1 * (90 - RIGHT(A))
PRINT #3, USING "G01 G90 C ##.###### F 300.0;"; CABS
PRINT #3, "M98 P172 L1;"

END SUB

SUB STARTFANUK

PRINT #3, ";"
PRINT #3, "G94 G20 G61;"

END SUB

SUB STOPFANUK

PRINT #3, "M54;"
PRINT #3, "M50;"
PRINT #3, "M58;"
PRINT #3, "M59;"
PRINT #3, "M51;"
PRINT #3, "M02;"
PRINT #3, "MOO;"
PRINT #3, ";"

END SUB

SUB XthenLEFT (A)

PRINT #3, USING "GOO G91 X  ##.###### F 1.0;"; XMOVE(A)
XPOS = XPOS + XMOVE(A)
```

```
CABS = -1 * (LEFT(A) + 90) + TOOLANG
PRINT #3, USING "G01 G90 C ####.###### F 300.0;"; CABS
PRINT #3, "M98 P171 L1;"

END SUB

SUB XthenRIGHT (A)
PRINT #3, USING "GOO G91 X ##.###### F 1.0;"; XMOVE(A)
XPOS = XPOS + XMOVE(A)
CABS = -1 * (90 - RIGHT(A))
PRINT #3, USING "G01 G90 C ####.###### F 300.0;"; CABS
PRINT #3, "M98 P171 L1;"

END SUB
```

CLAIMS:

1. An abrasive article (10) comprising a sheet-like structure having a major surface (16) having deployed in fixed position thereon a plurality of three-dimensional abrasive composites (12), each of said composites (12) comprising abrasive particles (13) dispersed in a binder (14) and having a substantially precise shape defined by a substantially distinct and discernible boundary (15) which includes substantially specific dimensions, wherein said precise shapes are not all identical.

2. The abrasive article of claim 1, wherein substantially all of said abrasive composites exist as pairs, each pair including two unmatched abrasive composites, one abrasive composite having a nonidentical shape to an adjacent abrasive composite.

3. The abrasive article of claim 1, wherein said abrasive composites include a first abrasive composite having a first precise shape having specific first dimensions and a second abrasive composite having a second precise shape and second specific dimensions wherein said first and the second specific dimensions are not the same.

4. The abrasive article of claim 3, wherein said first and second abrasive composites each has a boundary defined by at least four planar surfaces wherein adjacent planar surfaces meet to define an edge of a certain length, wherein at least one edge of said first composite has a length which is different from the length of all edges of the second composite.

5. The abrasive article of claim 4, wherein the length of said at least one edge of said first composite has a length which varies with respect to the length of any edge of said second composite in a ratio between 10:1 to 1:10, not inclusive of 1:1.

6. The abrasive article of claim 3, wherein said first and second abrasive composites have a first and second geometrical shape, respectively, which are nonidentical.

7. The abrasive article of claim 6, wherein said first and second geometrical shapes are selected from the group of geometrical shapes consisting of cubic, prismatic, conical, truncated conical, cylindrical, pyramidal, and truncated pyramidal.

8. The abrasive article of claim 3, wherein each of said abrasive composites has a boundary defined by at least four planar surfaces wherein adjacent planar surfaces meet an edge to define an angle of intersection therebetween, wherein at least one angle of intersection of said first abrasive composite is different from all of the angles of intersection of said second composite.

9. The abrasive article of claim 8, wherein no angle of intersection of adjacent planar surfaces in said first abrasive composite is equal to 0° or 90°.

10. The abrasive article of claim 8, wherein substantially all said abrasive composites have a pyramidal shape.

11. The abrasive article of claim 1, wherein said surface has a machine direction and opposite side

edges, each side edge being parallel to the machine direction axis and each side edge being respectively within a first and second imaginary plane each of which is perpendicular to said surface, a plurality of parallel elongate abrasive ridges deployed in fixed position on said surface, each ridge having a longitudinal axis located at its transverse center and extending along an imaginary line which intersects said first and second planes at an angle which is neither 0° nor 90°, and wherein each said abrasive ridge comprises a plurality of said three-dimensional abrasive composites which are intermittently spaced along said longitudinal axis.

12. The abrasive article of claim 11, wherein said plurality of parallel elongate abrasive ridges are deployed in first and second groups wherein said first and second groups are located at nonoverlapping locations in said machine direction or in a direction perpendicular to said machine direction of said major surface, wherein said longitudinal axis of at least one abrasive ridge within said first group extends along an imaginary line that intersects with an imaginary line extending from at least one longitudinal axis of an abrasive ridge in said second group.

13. The abrasive article of claim 11, wherein each abrasive ridge has a distal end spaced from said surface and each distal end extends to a third imaginary plane which is spaced from and parallel to said surface.

14. The abrasive article of claim 1, wherein each said abrasive composite has a distal end which is spaced from said surface a distance of about 50 micrometers to about 1020 micrometers.

15. The abrasive article of claim 1, wherein said abrasive composites are fixed on said major surface in a density of about 100 to about 10,000 abrasive composites/cm^2.

16. The abrasive article of claim 1, wherein said surface has a surface area, and substantially all said surface area is covered by said abrasive composites.

17. A method for manufacturing an abrasive article according to claim 1, comprising the steps of:

(a) preparing an abrasive slurry wherein the abrasive slurry comprises a plurality of abrasive particles dispersed in a binder precursor;

(b) providing a backing (41) having a front surface and a back surface; and a production tool (46) provided with a plurality of cavities in at least one major surface thereof, each cavity having a precise shape defined by a distinct and discernible boundary which includes specific dimensions, wherein said precise cavity shapes are not all identical;

(c) providing a means (44) to apply said abrasive slurry into a plurality of said cavities of said production tool (46);

(d) contacting said front surface of said backing with said production tool such that the abrasive slurry wets said front surface;

(e) solidifying the binder precursor to form a binder, whereupon solidification the abrasive slurry is converted into a plurality of abrasive composites; and

(f) separating said production tool from said backing after said solidifying to provide a plurality of abrasive composites as attached to said backing each having a precise shape defined by a distinct and discernable boundary which include specific dimensions,

wherein said precise abrasive composite shapes are not all identical.

18. A method of refining a workpiece with the abrasive article according to claim 1, comprising the steps of:

(a) bringing into frictional contact a workpiece surface and said abrasive article; and

(b) moving at least one of said abrasive article or said workpiece surface relative to the other such that the surface finish of said workpiece surface is reduced.

19. A production tool for manufacture of the abrasive composites according to claim 1, comprising a sheet-like structure having a plurality of cavities formed on a major surface thereof, each cavity having a precise shape defined by a distinct and discernible boundary which includes specific dimensions, wherein said precise cavity shapes are not all identical.

20. A method for making a master that is used to form a production tool according to claim 19, said master having a major surface extending within a first imaginary plane, comprising the steps of:

(1) determining angles corresponding to facing right and left planar surfaces of adjacent three-dimensional shapes and wherein each of said angles has a value as measured between its planar surface and a plane which extends in a normal direction to said master surface and contains an edge of said planar surface in contact with said surface, by the following substeps:

(i) selecting an angle value between, but not including, 0° and 90° to establish a first right half angle of a first right planar surface of a first right-

side three-dimensional shape with a random number generating means capable of randomly selecting an angle value between, but not including, 0° and 90°;

(ii) selecting an angle value between, but not including, 0° and 90° with said random number generating means to establish a first left half angle for a first left planar surface of a first left-side three-dimensional shape facing said first right planar surface of said first right-side three-dimensional shape;

(iii) proceeding along a first direction extending linearly within said first imaginary plane to a second left planar surface of a second left-side three-dimensional shape located adjacent said first left-side three-dimensional shape and using said random number generating means to select a value between, but not including, 0° and 90° to establish a second left planar angle for said second left planar surface;

(iv) using said random number generating means to select a value between, but not including, 0° and 90° for a second right planar surface of a second right-side three-dimensional shape facing said second left planar surface;

(v) proceeding along said first direction to a third right-side three-dimensional shape located adjacent said second right-side three-dimensional shape;

(vi) repeating said substeps (i), (ii), (iii), (iv), and (v), in that sequence, at least once;

(2) repeating step (1) except that the angles are determined for left and right planar surfaces of adjacent three-dimensional shapes deployed in two adjacent rows in a second direction extending linearly within said first imaginary plane, wherein said first and second directions intersect;

(3) using means to determine, for a given width of said surface of said master, locations of grooves required to be cut by a cutting means to form a series of intersecting grooves defining a plurality of precise three-dimensional shapes having said angles calculated by steps (1) and (2); and

(4) providing a cutting means to cut grooves in said surface of said master in correspondence to said angles calculated by steps (1) and (2) and said groove locations determined by step (3) to form a series of intersecting grooves which define a plurality of precise three-dimensional shapes upraised from said surface, each of said precise shapes being defined by a distinct and discernible boundary including specific dimensions, wherein not all said three-dimensional shapes are identical; and, optionally,

(5) applying a molten solidifiable polymeric resin on said surface of said master in a manner effective to flow into and conform to said three-dimensional shapes;

(6) solidifying said polymeric resin into a sheet-form; and

(7) removing said sheet-form polymeric resin from said surface of said master to form said production tool.

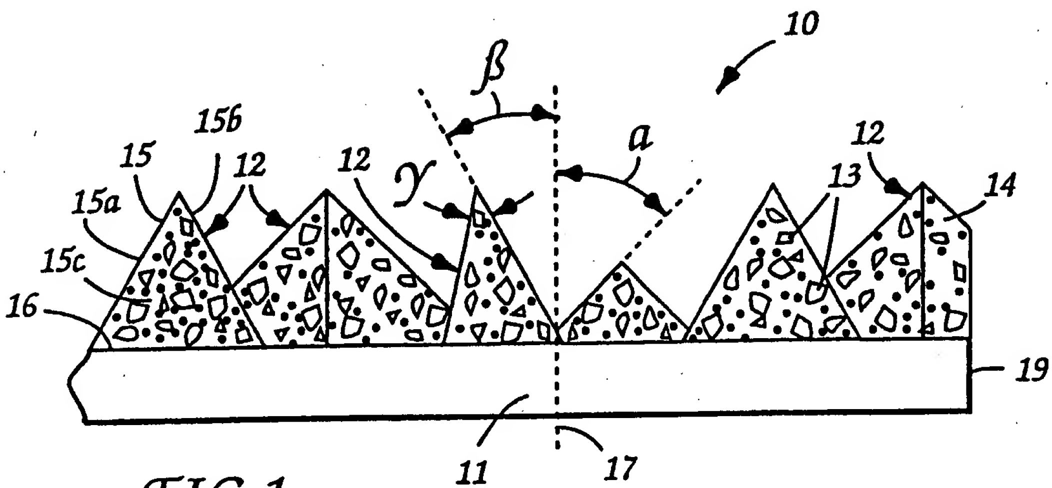

FIG.1

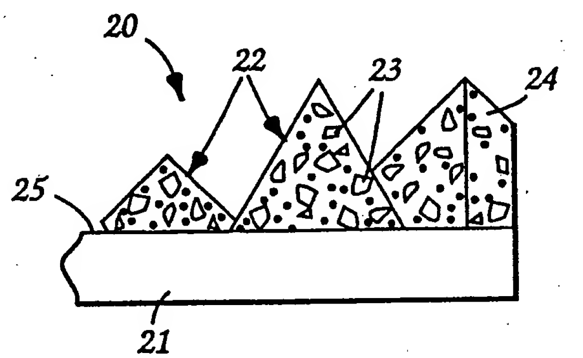

FIG.2

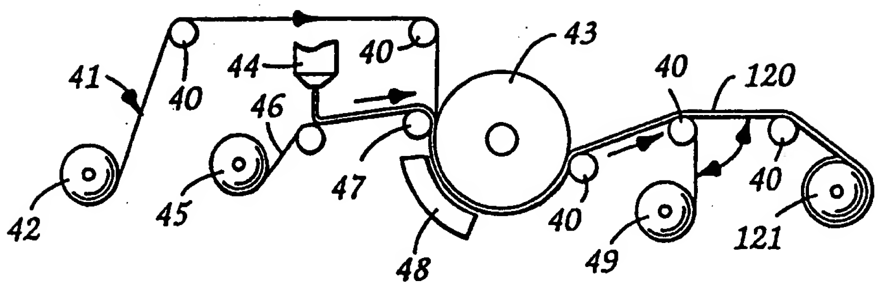
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FIG.3

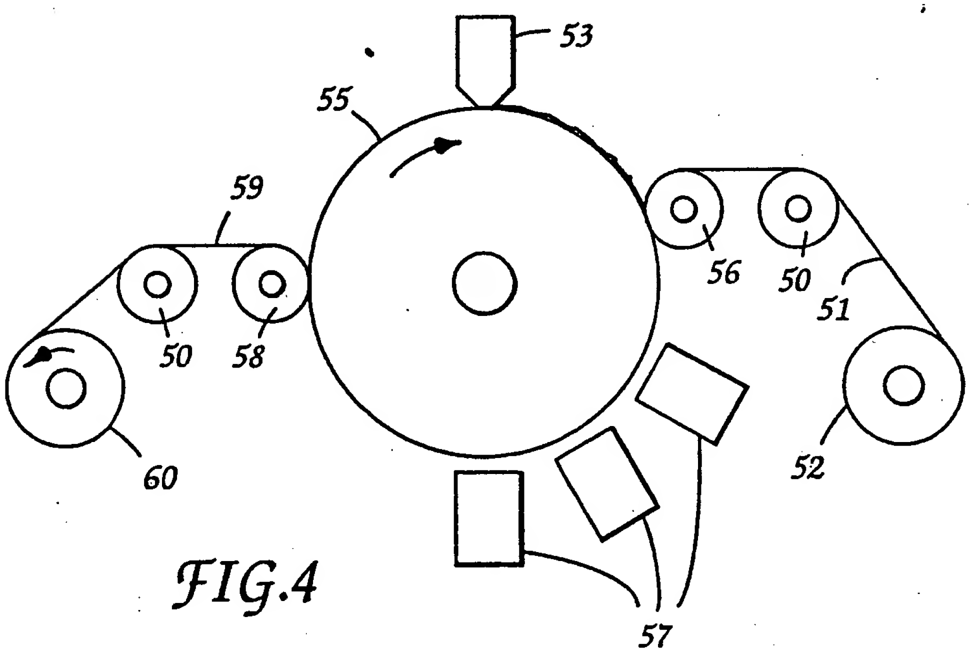
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FIG.4

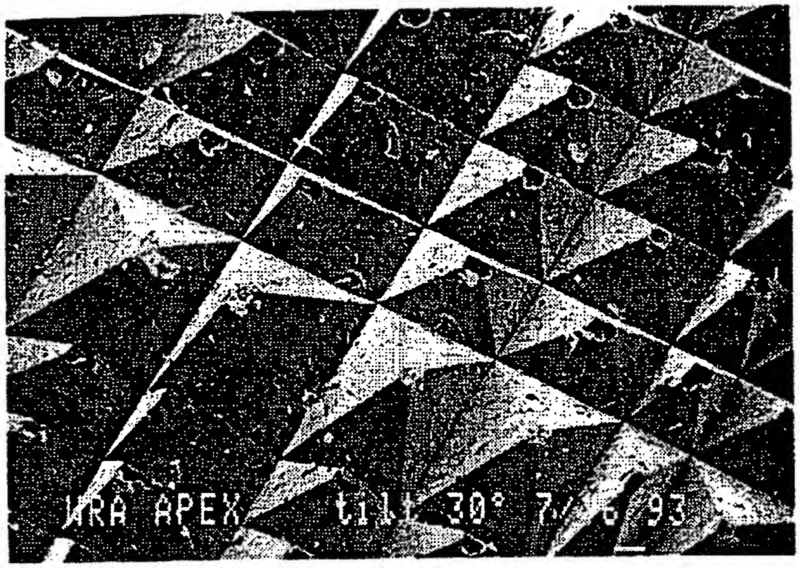
WRA APEX tilt 30° 7/16/93

FIG.5

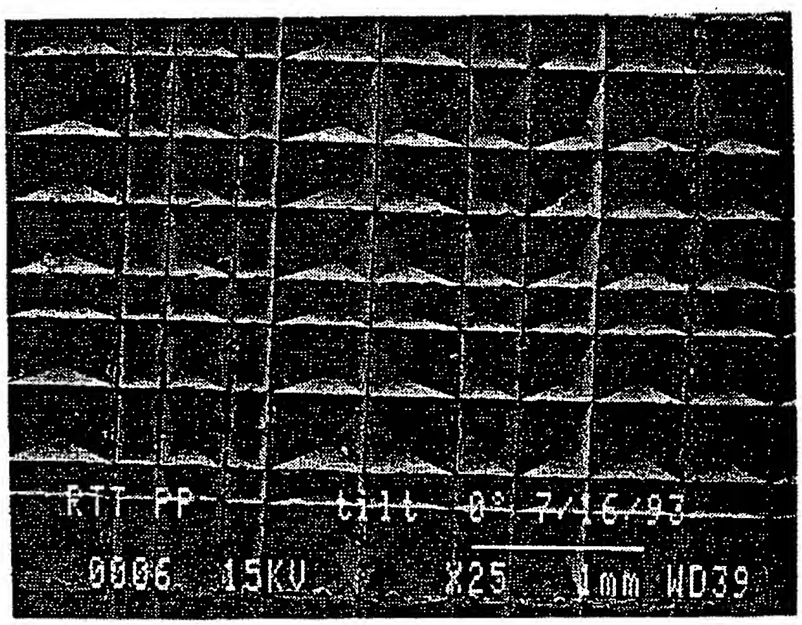
RTT PP tilt 0° 7/16/93
0006 15KV X25 1mm WD39

FIG.6

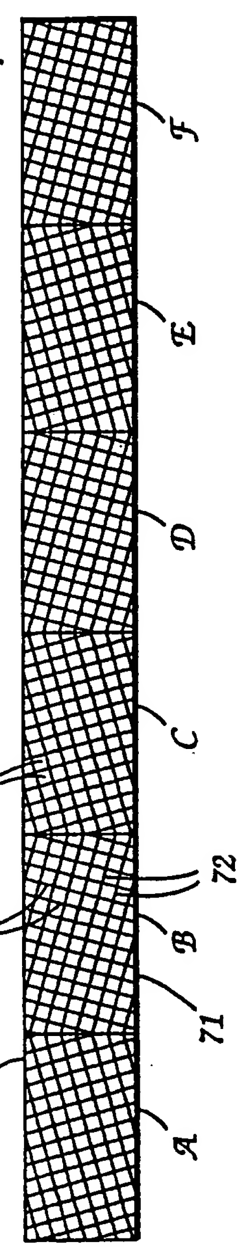

FIG.7

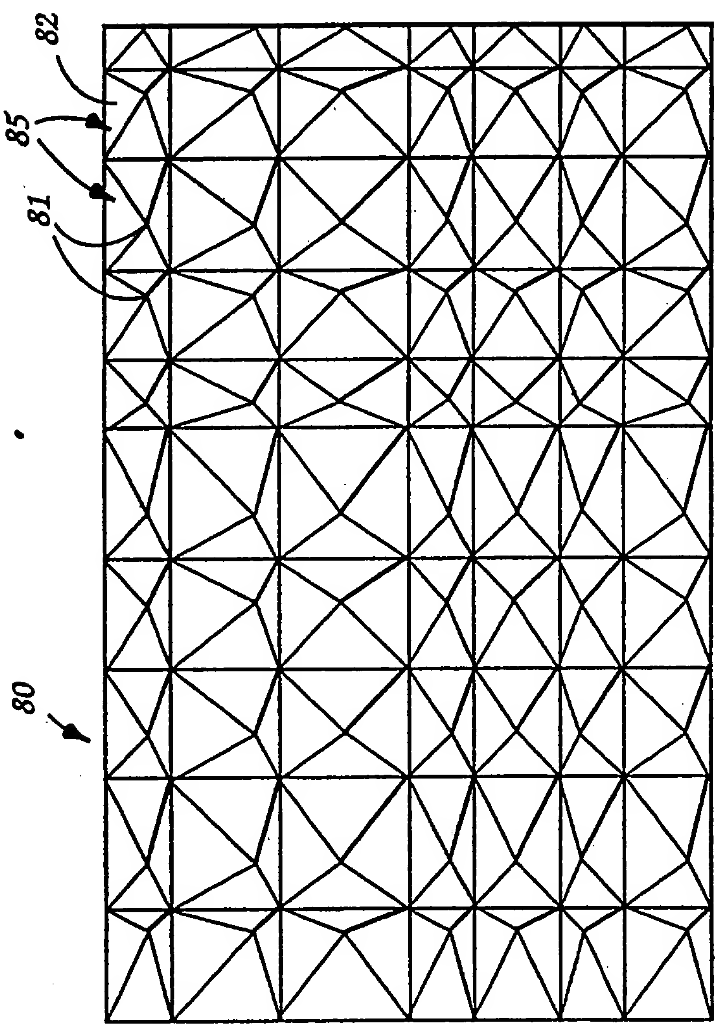

FIG.8

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 94/00754

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B24D11/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B24D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO,A,92 13680 (3 M CO) 20 August 1992 cited in the application see the whole document -----	1,17,19

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 June 1994	01.07.94

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 94/00754

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
WO-A-9213680	20-08-92	US-A-	5152917	06-10-92
		AU-A-	1240392	07-09-92
		BR-A-	9205596	26-04-94
		CN-A-	1064830	30-09-92
		EP-A-	0570457	24-11-93
		US-A-	5304223	19-04-94